

Sustainable Materials Management:

THE ROAD AHEAD



APPENDIX:

Relative Ranking Technical
Support Document

Appendix:
Sustainable Materials Management: The Road Ahead
Relative Ranking of Materials, Products, and Services Consumed in the U.S.
Using Selected Environmental Criteria
Technical Support Document

Introduction

The *Sustainable Materials Management: The Road Ahead* report (referred to as the “SMM Roadmap” herein) lays out a series of recommendations to shift our society from managing wastes to managing materials. In developing the Roadmap, an important question arose, where does one start? The U.S. economy is a highly complex and intertwined system in which a few hundred raw materials are transformed into thousands of products. It would be unrealistic to move toward life cycle materials management for all the materials and products consumed in an entire economy simultaneously. Thus, the Workgroup chose to recommend conducting a few well-chosen demonstration projects to show the value of life cycle materials management and gain greater insight on integrating policies and programs around materials management. This Technical Support Document lays out the analysis performed to identify potential candidates for the demonstration projects.

To help identify potential candidates for these demonstration projects, the 2020 Vision Relative Ranking of Materials, Products, and Services Using Selected Environmental Criteria (referred to as the “Relative Ranking Analysis” herein) used the best available data and a multi-factor analytical approach to relatively rank 480 materials, products, and services consumed in the U.S. economy along five environmental aspects:

- Environmental impact (13 different measures)
- Energy use
- Material use
- Material waste
- Water use

This information was used to help identify materials, products, and services where taking a materials management approach potentially could provide significant benefits across multiple environmental aspects. It is important to note that the relative ranking described herein reflects this objective – to help identify potential candidates for initial application of comprehensive materials management strategies. The 2020 Vision Relative Ranking Analysis does not rank materials, products, and services based on their actual or absolute human health and environmental impact, but rather on their potential to cause human health and environmental impacts. Relative ranking based on actual human health and environmental impact would require a common expression of impact (e.g., human health, ecosystem quality), complex modeling, and judgments regarding the impacts of highest priority. This is outside of the scope of the 2020 Vision Relative Ranking Analysis.

It is important to note that the 2020 Vision Relative Ranking Analysis focuses on the environmental implications of our collective consumption choices in the U.S and uses the 480 materials, products and services (which represent commodity groupings) identified by the

Bureau of Economic Analysis (BEA) and life cycle analysis to achieve this. The analysis is not intended to, nor can it single-out individual companies or individual products that have relatively high potential environmental impact or are relatively resource-intensive. Rather, the analysis is intended to help us better understand the relationships between our consumption choices and the environment, and help guide life cycle materials management strategies that could lessen the negative consequences of those choices.

The following sections describe the data sources used to analyze the different environmental aspects, methods used to cross-walk data to allow comparison across aspects, and the vector analysis methodology used to relatively-rank the 480 materials, products, and services.

Baseline List of Materials, Products, and Services

The data and information sources available to characterize the five environmental aspects use disparate classifications schemes, from very broad sectors as found in water use data to fairly disaggregated commodities as found in the Comprehensive Environmental Data Archive 3.0 (the tool used to characterize environmental impacts). Thus, a common or baseline list was needed to which data could be cross-walked.

The 2020 Vision Workgroup decided to use the list of 480 materials, products, and services (commodities) included in the U.S. Bureau of Economic Analysis' (BEA) 1998 input-output (I-O) tables as the baseline list. The BEA I-O accounts provide the framework for preparing the national and other economic accounts that are used for policy analysis, business planning, and other purposes. The I-O tables serve as both the data source and the framework used to estimate gross domestic product (GDP). The Federal Reserve formulates monetary policy and the U.S. Government formulates fiscal policy on the basis of GDP estimates and other economic statistics based on the I-O data. In business, macroeconomic and microeconomic forecasting models are built using the data from the I-O accounts.¹ The Workgroup decided that the use of the BEA I-O accounts would provide a sound foundation for the 2020 Vision Relative Ranking Analysis since it would take advantage of well-established and understood policy analysis methodologies.

Data from the BEA I-O accounts were used in conjunction with additional environmental and life-cycle data related to these materials, products, and services. All data sources were linked in a final analysis such that the 480 materials, products, and services could be ranked across all environmental aspects.

Using the BEA list of 480 materials, products and services minimized the amount of data set cross-walking and thus the uncertainties that arise from having to do so. Three sources of information were used for characterizing the 17 criteria considered in the analysis of each of the 480 materials, products, and services:

- The Comprehensive Environmental Data Archive v. 3.0 (CEDA 3.0) software tool was used to estimate 13 different environmental impacts criteria and the energy use criterion;
- The World Resources Institute (WRI) Material Flow Analysis (MFA) database was used to estimate material use and waste criteria; and

¹ BEA (2006). *Concepts and Methods of the U.S. I-O Accounts*. U.S. Department of Commerce, Bureau of Economic Analysis; Washington, DC.

- United States Geologic Service (USGS) water use data were used to estimate the water use criterion.

These sources of information were selected because they provide the best available data, most of which are from federal government sources, and coverage across the 17 criteria. Individual sources and the rationale for their selection are described in further detail in subsequent sections of this paper.

CEDA 3.0 contains estimates of impacts associated with the 480 commodities included in the BEA 1998 I-O tables. Therefore, results for the 13 environmental impact criteria and the energy use aspect were readily available for these 480 commodities without the need for further manipulation. In addition, the commodity classification system used for defining sectors for USGS water data was able to be readily aligned with this list of 480 commodities. The WRI MFA database focuses on materials, rather than a broader array of materials, products, and services, and its coding system reflects this different focus and scope. Therefore, it was decided that the most efficient and methodologically sound approach would be to use the 480 commodities in the BEA 1998 I-O tables as the common set of materials, products, and services to be considered in the 2020 Vision Relative Ranking Analysis.

Relative Ranking of Materials, Products and Services

A comprehensive ranking provides a comparison of the overall environmental attributes of materials, products and services relative to each other. The overall objective is to be able to give each item of interest a ranking that allows a direct comparison to other items of interest. This task is far easier when comparisons are made through a single criterion. However, when using many criteria and many data sets, all with differing units of measurement, the task becomes more challenging.

For example, in the context of this analysis, not all of the criteria are independent nor can they easily be expressed using a common set of measures relating to human health and ecosystem quality without subjective choices. For example, while the ranking of a particular product may be relatively more significant in terms of greenhouse gas emissions, it may generate relatively little waste or may be relatively benign in terms of aquatic toxicity. Complex models that would quantitatively unite the scope of criteria being considered herein using a common set of measures are elusive.

After careful consideration, the 2020 Vision Workgroup chose to use an applied vector analysis approach as the means to relatively rank the 480 materials, products and services across the five environmental aspects (and the associated 17 criteria) of interest. The vector analysis first looked at each of the criteria independently and identified the materials, products, and services that were most significant in terms of each criterion (e.g., the material, product, or service whose consumption generates the greatest amount of greenhouse gas emissions). The extent to which each material, product, or service differed from the overall group of 480 materials, products, and services was quantified using a statistical measure. Then, the 480 materials, products, and services were ranked across all of the 17 criteria and the influence of each criterion on the overall ranking was developed using vector calculus.

Using this approach, some materials, products, and services may be ranked relatively high based on more than one criterion, whereas others may be dominated by a single criterion. Vector analysis provides a transparent, quantitative approach for identifying the criterion or criteria that contribute the most or are the drivers behind the rankings, providing an indication of the relative effect of different criteria.

The vector approach allows for a quantitative comparison of the 480 materials, products, and services across the 17 criteria in a manner that reflects the underlying data. Because it ignores the interdependence of the different criteria and weighs all criteria equally, it does not provide an indication of overall relative human health or environmental impact. However, because it highlights the most significant materials, products, and services within each criterion and provides a mechanism for highlighting materials, products, and services that are significant across multiple criteria, it meets the objectives of the 2020 Vision Relative Ranking Analysis – to help identify materials, products, and services where materials management strategies potentially could provide significant benefits across multiple aspects.

Three System Perspectives Analyzed

At the heart of the 2020 Vision materials management approach is the concept of “life cycle” and viewing the entire system. Life cycle refers to the major activities that occur from the point at which raw materials are acquired through processing, manufacture, use, and end-of-life management. In this analysis, the system of interest was the entire U.S. economy and the materials, products and services consumed. The environmental aspects associated with the life cycle of a material, product, or service can be evaluated using the concepts and tools of life cycle assessment (LCA).² Traditional “economy-wide” LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the life cycle of final products and services consumed in the economy. For this analysis, LCA concepts were also used to assess the other four environmental aspects – material use, material waste, water use, and energy use.

Mechanistically, input-output LCA estimates the environmental aspects associated with each stage, and movement between, in a product or service’s lifecycle and “passes” those aspects through to more refined products and services using I-O tables until the aspects are fully accounted for in final products and services delivered to consumers. For example, in the production of fluid milk, water is used to grow feed grains that are then used to sustain the cattle used to produce raw milk. Water is used to manufacture fluid milk from raw milk and to manufacture the containers within which the milk is transported for final consumption. Water is used in the recycling and/or disposal of used milk containers.

Using economic I-O tables, a percentage of the total water used in growing feed grains is allocated to the production of raw milk based on the percentage of all feed grains consumed by dairy farms. Although this water is not directly used by dairy farms, for LCA purposes, it is considered “embedded” in the production of dairy farm products. Similarly, water directly used in sustaining dairy cattle and producing raw milk, as well as “embedded water” from feed grains and other materials and products consumed by dairy farms, are allocated to the product “fluid milk” based on the percentage of raw milk consumed by fluid milk producers. Final life cycle

² See, for example, EPA (2006). *Life Cycle Assessment Principles and Practice*. United States Environmental Protection Agency, Washington, DC. EPA/600/R06/060.

water use is calculated as the percentage of fluid milk that is directly consumed by end consumers (e.g., as opposed to fluid milk consumed in the production of cheese) and includes both water directly used in the production of fluid milk and embedded water use.

However, this process of passing all environmental aspects down through each life cycle stage and embedding them in the final products or services consumed may hide significant impacts of upstream stages, especially when the outputs of those stages become widely dispersed across a large number of different final products. Each of those final products will have separate material composition profiles and life cycles. For example, copper mining potentially contributes significantly to environmental and human health impacts. Using a product or final consumption perspective, these potential impacts would be dispersed among the thousands of products in which copper is used, such as currency, batteries, circuits, industrial components, telecommunications equipment, roofing, household items, piping, and a wide variety of electronic products. The life-cycle impacts associated with creating those products would be captured, including the embedded impacts associated with copper mining, but because copper comprises such a small portion of the individual products and because the copper material is so widely dispersed among these products, the substantial impacts of copper mining as a whole would be hidden.

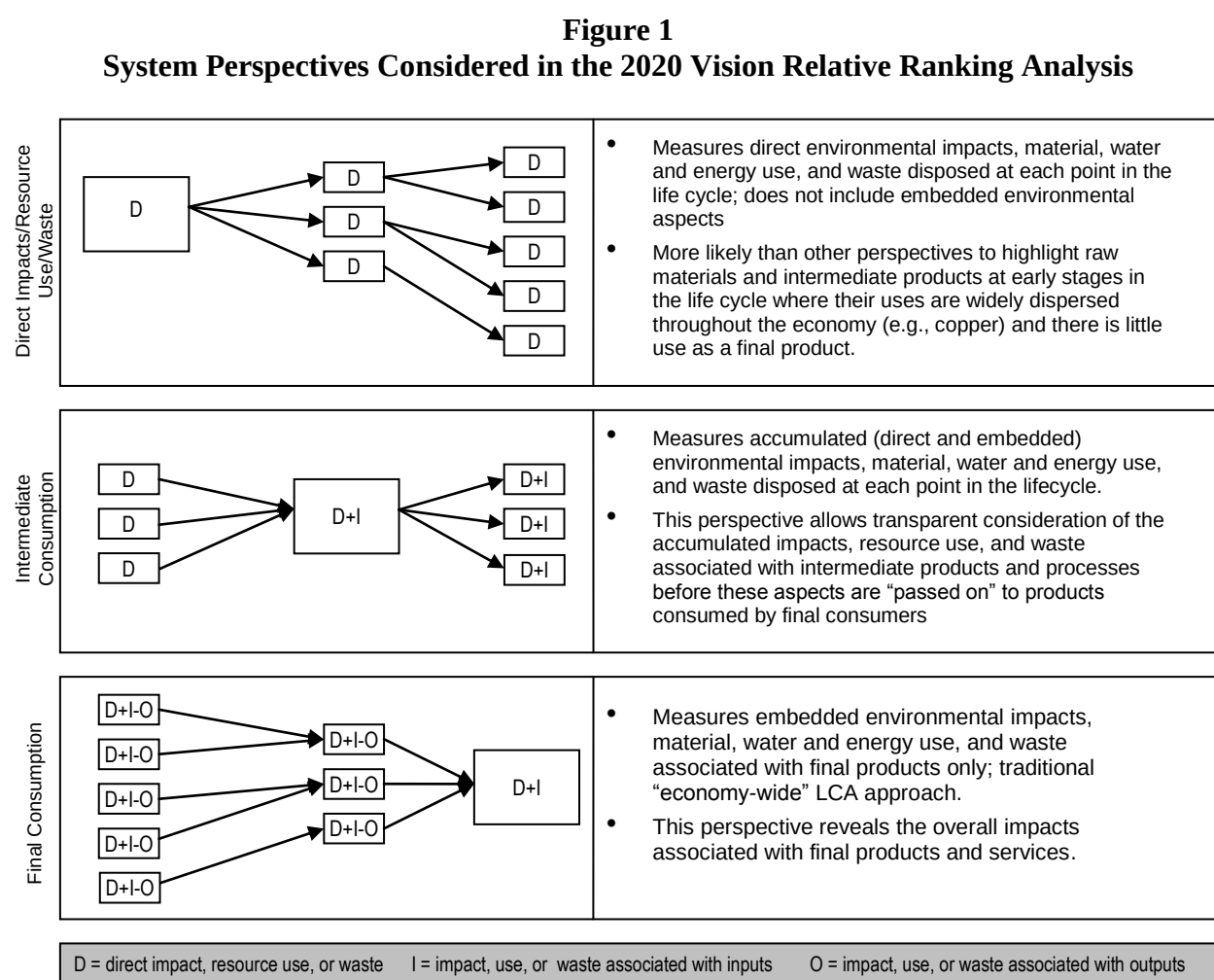
Therefore, this analysis examined the U.S. economy from three system perspectives believed to offer a higher likelihood of revealing potential environmental aspects that might be associated with earlier life-cycle stages such as extraction (e.g., copper ore) or initial material processing (e.g., smelting) and middle stages such as manufacturing, as well as final products or services. They included:

- Direct impact/resource use/waste – environmental aspects directly associated with each stage of the life cycle: extraction of raw materials, production, and consumption of products and services. This perspective does not include environmental aspects embedded in a material, product, or service. Using the fluid milk example above, direct water use associated with raw milk would include water used directly to produce raw milk but would not include water used to grow feed grains.
- Intermediate consumption – environmental aspects directly associated with materials, products, and services plus embedded environmental aspects at each stage of the life cycle. This perspective provides insights into the environmental aspects that have “accumulated” to a certain point in the life cycle, regardless of whether it is the point of consumption by end consumers (e.g., households) or intermediate consumers (e.g., manufacturers). Using the fluid milk example above, water use associated with raw milk from the intermediate consumption perspective would include water used directly in producing raw milk plus water embedded in the raw milk from sources such as feed grains.
- Final consumption – environmental aspects directly associated with materials, products, and services plus “embedded” environmental aspects at the point of final consumption. Unlike the intermediate perspective, the final consumption perspective does not “accumulate” environmental aspects at stages prior to final consumption. Rather, all aspects not associated with final consumption are “passed through” to downstream materials, products, and services. Using the example above, water use associated with fluid milk would include water embedded in that percentage of fluid milk consumed by

households. From the final consumption perspective, water use associated with fluid milk that is an intermediate product (e.g., used in the production of cheese) is not counted in the life cycle water use for fluid milk but, rather, is counted as embedded water in the downstream products (e.g., in the life cycle water use for cheese directly consumed by households).

The 2020 Vision Workgroup decided to analyze and consider all three of these perspectives based on their potential to provide a greater understanding of environmental aspects associated with materials, products and services across the U.S. economy.

Figure 1 summarizes the three system perspectives and presents a summary of the types of situations where each perspective might highlight materials, products, and services where the others would not.



For the purposes of this analysis, the 2020 Vision Workgroup defined final consumption as that which is ultimately consumed by both households and government.

The three system perspectives differ in that the direct impact/resource use/waste and final consumption perspectives allocate the environmental aspects associated with consumption of

products and services in the U.S. economy in a mutually exclusive, collectively exhaustive manner. The sum of an environmental aspect using either of these approaches across the 480 materials, products, and services is equal and approximates the overall aspect in terms of total consumption in the U.S.

The intermediate consumption perspective, on the other hand, does not attempt to allocate the total life-cycle aspects of U.S. household and government consumption in a mutually exclusive, collectively exhaustive way, but rather, shows accumulated aspects of a stage and then passes them on to the next stage up to the point of sale of the material, product, or service. The results of the intermediate consumption analysis cannot be summed across materials, products, and services in a meaningful way.

The Five Environmental Aspects

The Comprehensive Environmental Data Archive (CEDA 3.0) software tool was used to develop and allocate estimates of environmental impact based on standard Life Cycle Impact Assessment (LCIA) methods. For the remaining aspects, data sources were identified and were cross-walked to the 494 industries that correspond to the 480 commodities in the BEA I-O accounts. An extension to CEDA 3.0 was then used to allocate material use, material waste, water use, and energy use across the 480 materials, products, and services for the three system perspectives.³ The following subsections describe the data sources, cross-walking, and allocation methods used to develop relative estimates of environmental impact, material use, material waste, water use, and energy use for the baseline list of 480 materials, products, and services.

Environmental Impact

CEDA 3.0 is a software tool used for environmental input-output analysis, lifecycle analysis (LCA), and other applications.⁴ CEDA 3.0 was chosen for the 2020 Vision Relative Ranking Analysis due to its breadth—covering the 480 commodities from the 1998 BEA accounts—and its depth—covering around 90 characterization methods commonly used in LCIA, 13 of which were considered in this analysis. CEDA 3.0 is well documented and its assumptions and methods are transparent; it has undergone significant independent peer review; it has been used for similar economy-wide such as the European Commission’s Environmental Impact of Products (EIPRO) study; and it incorporates state-of-the art methods and best available government and other public data.

CEDA 3.0 includes three database modules: 1) economic input-output (I-O), 2) environmental interventions; and 3) characterization factors. The economic I-O module contains information

³ The core of the BEA I-O accounts consists of two tables: a “make” table and a “use” table. Each table includes information about both the “industries” that operate in the U.S. economy and the “commodities” that these industries use and produce. The 1998 *make table* includes information on 480 commodities produced by 494 industries. The 1998 *use table* shows the use of these 480 commodities by the 494 industries as well as end-users – households and government. For more information, see BEA (2006), *Concepts and Methods of the U.S. I-O Accounts*, U.S. Department of Commerce, Bureau of Economic Analysis, Washington, DC. For the purposes of this analysis, resource use and waste data were first aligned with the 494 BEA-defined industries. The *make and use tables* were used via CEDA 3.0 to associate resource use and waste data with the 480 BEA-defined commodities that were used in this analysis as the baseline list of “materials, products, and services.”

⁴ Suh, Sangwon (2004). *CEDA 3.0 User’s Guide*. CML, Leiden University, Leiden, The Netherlands.

on the structure of inter-industry exchanges of materials and energy throughout the supply chains of the baseline 480 commodities. It is used, in conjunction with CEDA's other two modules, to estimate environmental impacts associated with these commodities. Commodity-to-commodity relationships are based on the 1998 annual I-O tables and procedures that follow the standard make and use framework defined by BEA. However, the 1998 annual I-O tables do not provide the capital flow data that were needed for the analyses. Therefore, the BEA capital flow matrix for 1992 was used, and the amount of capital goods used by each sector was inflated or deflated depending on price change information and gross output differences observed between 1992 and 1998.

In the context of CEDA 3.0 and similar LCA tools, "environmental intervention" is a general term used to capture a range of interactions between humans and the environment, including resource extraction, land use, and emissions to air, water, and land.⁵ The environmental intervention module in CEDA 3.0 includes six resource extraction categories (e.g., coal, iron ore), a land use category, and over 1,300 categories linking specific chemical substances (e.g., benzene, mercury) to four media (i.e., industrial soil, agricultural soil, freshwater, and air). The environmental interventions data are linked to the baseline 480 commodities using information derived from environmental databases covering factors ranging from toxic releases to energy consumption and land use.⁶

The CEDA 3.0 characterization factors module contains information to aggregate environmental intervention data into environmental impact scores according to the LCA methodologies developed by the Centre for Environmental Science, Leiden University (CML) and other widely used methods.⁷ The relationships established in the economic I-O module are used with the environmental interventions module in order to estimate environmental impacts associated with each of the 480 materials, products, and services according to the perspective of interest (i.e., direct impact/use/waste, intermediate consumption, or final consumption) and methodologies established in the characterization module.

For the purpose of the 2020 Vision Relative Ranking Analysis, the following thirteen impact criteria were used to characterize the environmental impacts associated with the 480 materials, products, and services (see Guinée 2002 for specific definitions):

- Abiotic depletion potential (ADP)
- Land use (increase of land competition) (LUC)
- Global warming potential (GWP)
- Ozone layer depletion potential (ODP)
- Human toxicity potential (HTP)
- Freshwater aquatic toxicity potential (FAETP)
- Marine aquatic toxicity potential (MAETP)
- Terrestrial ecotoxicity potential (TETP)
- Freshwater sedimental ecotoxicity potential (FSETP)

⁵ ISO (1997). 14040:1997. Environmental management - life cycle assessment – principles and framework. Geneva, Switzerland, International Organization for Standardization (ISO).

⁶ Suh, Sangwon (2004).

⁷ Guinée, J.B. (2002). *Handbook on Lifecycle Assessment, Operational Guide to the ISO Standards*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

- Marine sedimental ecotoxicity potential (MSETP)
- Photochemical oxidation (high NO_x) potential (POCP)
- Acidification potential (AP)
- Eutrophication potential (EP)

Because CEDA 3.0 is already capable of estimating potential environmental impacts for all of the 480 commodities defined as the baseline for the 2020 Vision Relative Ranking Analysis, no re-coding or allocation of these results was necessary. As a result, CEDA 3.0 output was used directly in the vector analysis.

For the full CEDA 3.0 environmental impact data incorporated in the 2020 Visions Relative Ranking Analysis, please see the spreadsheet entitled “2020 Vision Multi-Factor Scoring_May09.xls.”

Material Use

For the material use aspect, the 2020 Vision Relative Ranking Analysis used World Resources Institute (WRI) Materials Flow Analysis (MFA) data. MFA data were developed by WRI as a comprehensive estimation of material flows for over 160 primary materials consumed in the U.S. economy from 1975 through 2000, covering four principal sectors: agriculture, forestry, non-renewable organic materials (e.g., fossil fuels), and metals and minerals. The WRI MFA data were captured in the 2020 analyses by cross-walking the WRI material classification system with the BEA-defined industries and by using an extension to CEDA 3.0 to allocate material use to the 480 BEA-defined commodities for the three system perspectives.

The WRI MFA database covers physical resources entering the U.S. economy and follows them as they undergo successive physical and chemical transformations throughout respective material life cycles. The database systematically categorizes materials flowing through the U.S. economy, emphasizing transparency in documenting data sources and any assumptions made in estimating the flows.⁸ Data for this database come from government offices, trade associations, and independent research institutes and, where appropriate, supplemented by estimates from technical experts. WRI MFA data represent the most comprehensive accounting of material flows currently available across the U.S. economy. The 2020 Vision workgroup considered the integration of the 2020 Vision Relative Ranking Analysis with the WRI MFA data to be a vital component of the analyses, despite the challenges involved.

For the purposes of the 2020 Vision Relative Ranking Analysis, *material use* was defined to be consistent with the direct material consumption (DMC) measure used by WRI. WRI defines DMC as the “sum of all inputs that enter the economy.” This measure is comprised of all raw materials required to produce commodities in the economy, including domestically extracted and imported raw materials, less processing wastes and exports of processed materials. This is comparable to the CEDA 3.0 approach, in that CEDA 3.0 estimates impacts associated with domestic consumption. WRI calculates DMC by sector, and the values, reported in thousand

⁸ WRI (2008). *Material Flows in the United States, A Physical Accounting of the U.S. Industrial Economy*. World Resources Institute, Washington, DC.

metric tons, are approximately equal to the sum of the “uses” estimated for each of the WRI-defined materials in the WRI MFA database.⁹

For the 2020 analyses, WRI materials were aligned with the BEA industries that produce the material. The BEA I-O tables define relationships among industries by quantifying how the output from extraction industries is used as input to subsequent processing and service industries. The WRI database defines materials both in terms of extracted raw materials and minimally processed materials. Thus, the two systems provide alternative definitions of the material flow during extraction and initial production stages, where the BEA I-O tables quantify these flows based on production value, and the WRI database quantifies these flows based on physical units (i.e., weight).

The BEA industry classification system includes a limited number of categories for extraction industries, in some cases, representing a far less detailed breakdown of materials than the WRI MFA data. In such cases, efforts were made to align the WRI materials with initial processing industries, rather than extraction industries. For example, rather than align the WRI materials, “lumber” and “paper and board” with the BEA industry “forestry products,” “lumber” was aligned with the BEA industry “sawmills and planing mills” and “paper and board” was aligned with the BEA industry “pulp mills.”

Decisions regarding correspondence between WRI uses and BEA industries were based on information derived from the industry classification hierarchies reflected in the NAICS and SIC systems and the following other key sources:

- USFS (2001). *U.S. Timber Production, Trade, Consumption, and Price Statistics, 1965–1999*. U.S. Department of Agriculture, U.S. Forest Service (forestry)
- U.S. Census (2003). *Value of Construction Put in Place, May 2003, Annual* (earth moving and infrastructure)
- U.S. Geological Survey (USGS), Mineral Commodity Series (metals and minerals)

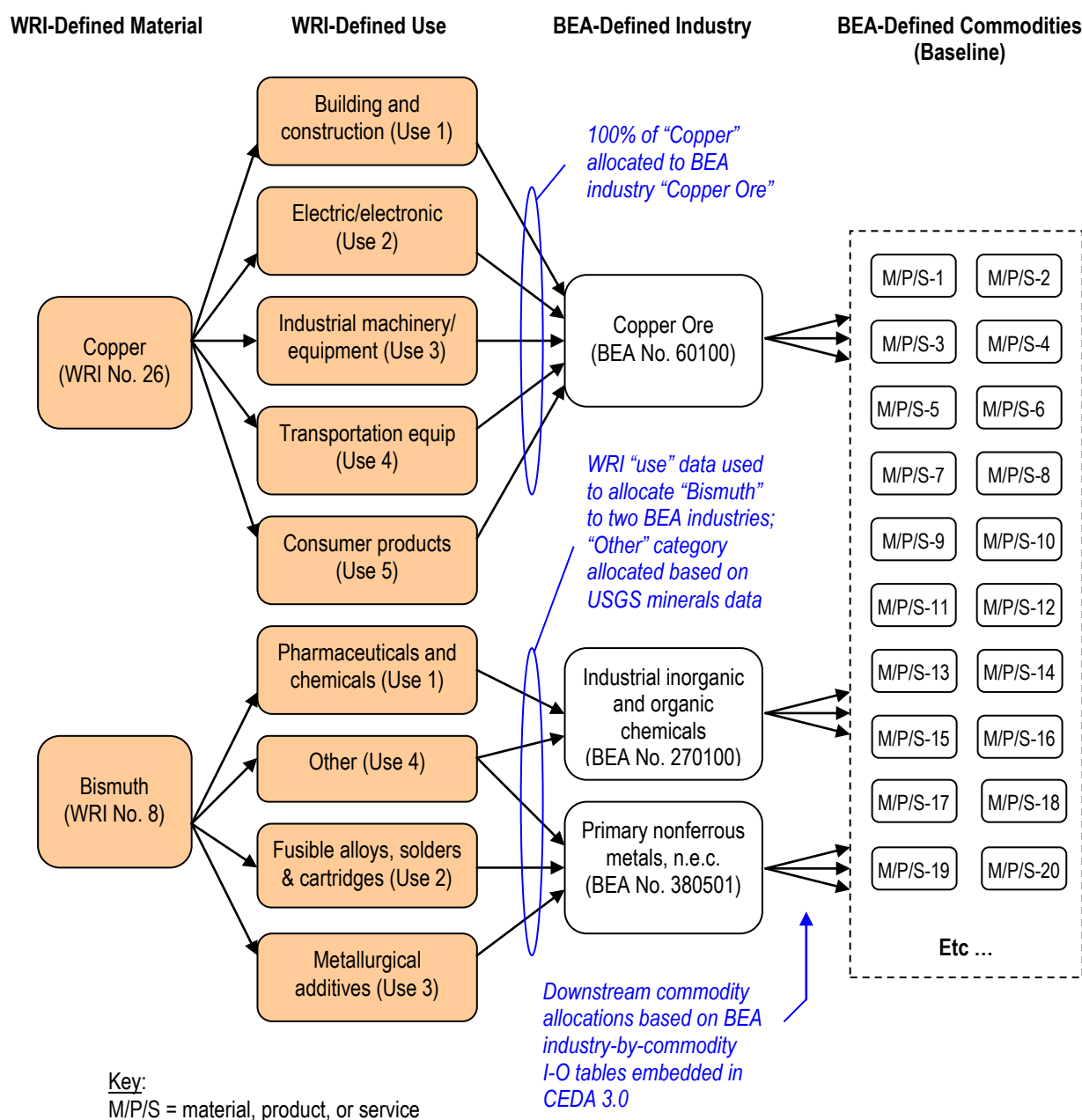
WRI material flows for the year 1998 were allocated according to their correspondence between each of the WRI materials and respective BEA industries. For example, where one or more WRI materials were associated with a single BEA industry, 100% of the WRI material flow was allocated to the industry. Where a single WRI material was associated with more than one BEA industry, the material flow was allocated among the BEA industries according to each industry’s respective share of total production, using BEA economic I-O data.

For example, the WRI database allocates “copper” among five different uses, including uses in building materials, electrical components, equipment, and consumer products. However, because of the close correspondence between the WRI material and BEA industry definitions, 100% of the WRI MFA data were allocated to BEA industry “copper ore.” Allocation among uses was accomplished using the BEA I-O tables embedded in CEDA 3.0.

⁹ The WRI MFA database accounts for material flows in terms of specific uses associated with a material. For example, the WRI database tracks five different uses of the mineral boron: glass products, soaps and detergents, agriculture, fire retardants, and other. Tracking material flows based on specific uses provides greater resolution than if the flows were tracked only at the material level (e.g., overall use of boron).

In another example, the WRI database allocates “bismuth” among four different uses, including uses of bismuth in metal alloys and chemical applications. Because bismuth is a by-product of lead, copper, and tin ore smelting, it can be associated with the BEA industry “primary nonferrous metals, n.e.c.” However, because this is a broad category, the quantity of bismuth associated with the WRI use “pharmaceuticals and chemicals” was allocated instead to BEA industry “industrial inorganic and organic chemicals.” These two examples and the overall approach to the WRI-BEA crosswalk are illustrated in Figure 2.

Figure 2
Approach for Allocating WRI Materials to BEA Industries and Commodities



Once the linkage between the WRI material and BEA industries was established, BEA I-O data were used to allocate the materials to the 480 BEA-defined commodities based on the three system perspectives (direct impact/resource use/waste, intermediate consumption, and final consumption) using the CEDA 3.0 methodology. In this way, the BEA I-O data was substituted for WRI-defined “uses.” While some detail afforded by the WRI data was lost, this enabled a consistent basis for comparing materials, products, and services across material use and other criteria and, thus, supported the primary objectives of the 2020 Vision Relative Ranking Analysis.

The crosswalk between the WRI-defined materials and BEA-defined industries is contained in the spreadsheet entitled “WRI-BEA Xwalk_May09.xls.” Calculated material use values for the 480 BEA commodities are contained in the spreadsheet, “2020 Vision Multi-Factor Scoring_May09.xls.”

Material Waste

The 2020 Vision Relative Ranking Analysis incorporated WRI material waste data using the same methodology used for material use. For the purposes of the 2020 Vision Relative Ranking Analysis, material waste was defined to be consistent with the direct process output (DPO) measure used by WRI. WRI defines DPO as the “materials that are consumed in the domestic economy and subsequently flow to the domestic environment.” This measure is comprised of all materials that are consumed in the U.S. economy and “exit” (e.g., through disposal in a landfill) within 30 years after entry.¹⁰ Using the WRI-BEA crosswalk, estimates of material waste were allocated to the 480 materials, products, and services for the three system perspectives using an extension to CEDA 3.0.

The crosswalk between the WRI-defined materials and BEA-defined industries is contained in the spreadsheet entitled “WRI-BEA XwalkMay09.xls.” Calculated material waste values for the 480 BEA commodities are contained in the spreadsheet, “2020 Vision Multi-Factor Scoring_May09.xls.”

Water Use

The 2020 Vision Relative Ranking Analysis incorporated aggregated USGS water use data allocated among the BEA-defined industries using data from multiple, sector-specific sources. Once water use data was linked to BEA industries, water use was allocated to the 480 materials, products, and services for the three system perspectives using an extension to CEDA 3.0.

Historically, USGS has tracked national water use data within nine general sectors: domestic, livestock, irrigation, aquaculture, mining, industrial, commercial, hydroelectric power generation, and thermoelectric power generation. USGS relies on data collected at statewide levels, and recent statistics do not exist regarding the National break-down in water use within

¹⁰ It is equal to the DMC measure used as the basis for defining “material use” for the 2020 Vision Relative Ranking Analysis, less material that remains in the economy for over 30 years (called “net additions to stock”), less material that is recycled.

certain sectors. The water use data were disaggregated to the level of the 494 BEA-defined industries using the following steps:

- BEA industries associated with each of the USGS-defined sectors were identified based on USGS water data collection guidelines, which contain detailed lists of industries included in each of the USGS-defined sectors.¹¹
- Sources of information that provide water use statistics at a detailed level were identified for each sector, and water use categories in these sources were cross-walked with USGS sectors and BEA industries.
- Water use allocations were developed for all BEA-defined industries associated with each of the USGS sectors, using water use statistics from detailed sources.
- Within-sector allocations were applied to total USGS water use data by sector to estimate total water use by each of the BEA-defined industries.

The following sources of information were used to allocate water use data within sectors:

- Irrigation: USDA (1999). *1997 Census of Agriculture, 1998 Farm and Ranch Irrigation Survey*. National Agricultural Statistics Service.
- Mining: US Census (1985). *1982 Census of Mineral Industries*. US Department of Commerce, Bureau of the Census.
- Industrial: US Census (1986). *1982 Census of Manufacturers*. US Department of Commerce, Bureau of the Census.
- Commercial:
 - Pacific Institute (2003). *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. Pacific Institute for Studies in Development, Environment, and Security, Oakland, CA.
 - Dziegielewski, B. et al. (2002). *Analysis of Water Use Trends in the United States: 1950–1995*. Southern Illinois University at Carbondale, Carbondale, IL February 28, 2002.

For the livestock sector (involving four BEA-defined industries), BEA I-O production value data were used to allocate water use within the sector. Water use allocations were not derived for the aquaculture sector because there were no corresponding BEA industries. Water used for power generation was allocated to the three BEA industries, “Electric services (utilities),” “Federal electric utilities,” and “State and local government electric utilities” based on generating capacity data from the U.S. Energy Information Administration (EIA). Where there were gaps within sectors (e.g., because data were not published in order to protect confidential business information), water use allocation was estimated based on other water use data for similar industries or other sources of information.

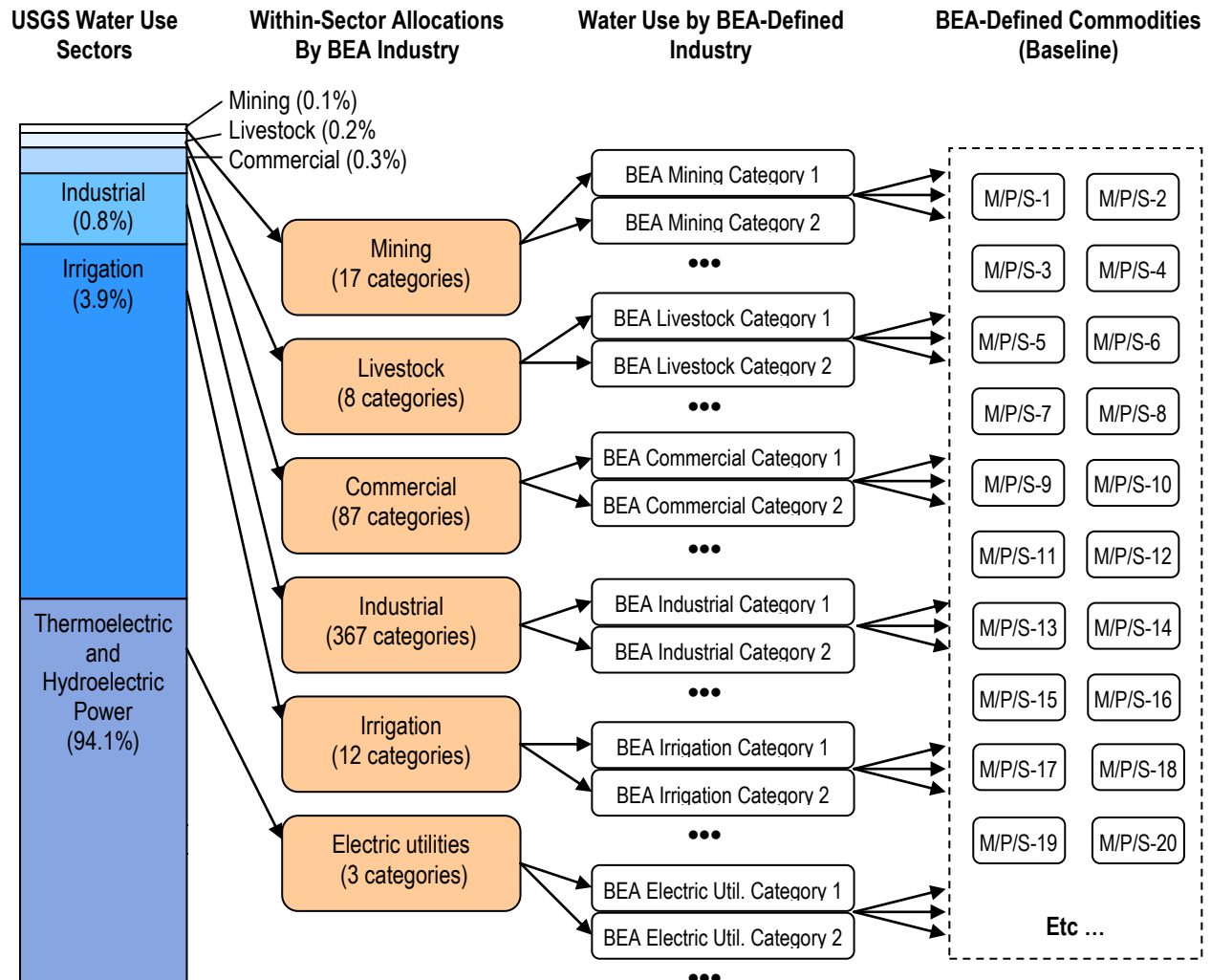
Using the disaggregated USGS-BEA crosswalk, estimates of water use were allocated to the 480 materials, products, and services for the three system perspectives using the BEA industry-by-commodity I-O tables and LCA methodology embedded in CEDA 3.0.

¹¹ USGS (2000). *Guidelines for Preparation of State Water-Use Estimates for 2000*. US Department of the Interior, US Geologic Survey, Washington, DC.

It is important to note that although the data used to allocate water use within the industrial and commercial sectors is outdated, it was determined that the 2020 Vision Relative Ranking Analysis was insensitive to this issue. After the hydroelectric thermoelectric power sectors, the agricultural sector is the dominant sector in terms of water use; therefore, in addition to electric utilities, the vector analysis will tend to highlight agricultural materials, products, and services. Changes in water use allocations within the highly disaggregated industrial and commercial sectors will have little effect on this result. The basis for this conclusion is shown in Figure 3.

For the full water crosswalk for the 494 BEA industries, please see, “Water Crosswalk_May09.” Calculated water use values for the 480 baseline materials, products, and services are contained in the spreadsheet, “2020 Vision Multi-Factor Scoring_May09.xls.”

Figure 3
Allocation Methodology for Calculating Water Use
Associated with BEA Industries and Commodities



Because commercial and industrial sector water use is a relatively small percentage of the total and because these sectors are highly disaggregated, overall allocation of water use among the BEA-defined categories will be relatively insensitive to shifts within these sectors.

Allocation of total water use to each BEA-defined industry is calculated as:

$$(S\%)*(C\%)*(Total\ U.S.\ Water\ Use)$$

Where:

S% = Percent water use of sector

C% = Percent water use within sector

Key: M/P/S = material, product, or service

Energy Use

For the 2020 Vision Relative Ranking Analysis, energy use was estimated and allocated to the 480 materials, products, and services using an extension to the CEDA 3.0 software tool. In 1998, the total energy consumed in the U.S. amounted to 95.1 quadrillion British Thermal Units (QBtu).¹² Based on data contained in the CEDA extension, the largest source of energy consumed in 1998 was petroleum, followed by natural gas and coal (see Figure 4). For the purposes of the 2020 Vision Relative Ranking Analysis, total net primary energy consumption data were assigned to the point within the economy at which energy was consumed, so that the resulting data represent the total embodied energy, including renewable energy, in products and services in the U.S.

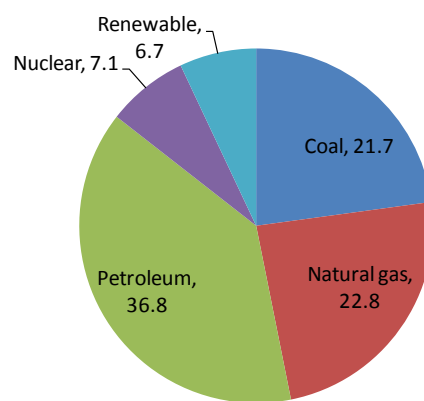


Figure 4. Energy consumption (QBtu) in the U.S. by sources (1998)

The following energy types were included in the analysis:

- Fossil energy – coal, natural gas, and petroleum
- Nuclear energy
- Renewable energy – hydropower, biomass, and solar

Geothermal energy was not included in the analysis due to the uncertainties in identifying the end-users, which are geographically constrained. Total amount of geothermal energy consumption in 1998 was less than 0.5% of the total energy consumption.

The following procedure was used to allocate energy consumption data to the materials, products, and services used in the analysis:

- Total energy consumption by sector data were compiled at the most detailed level available from EIA.
- Where there was a one-to-one match between the end-use category defined by EIA and a BEA commodity included in the 1998 I-O tables, the data were directly applied to the

¹² EIA (2008). *Annual Energy Review (AER)*. Energy Information Administration, Washington, DC: Department of Energy.

commodity. For example, EIA specifies the amount of coal use by blast furnaces and power generation, which is a distinct BEA-defined commodity used in CEDA 3.0.

- If an end-use category defined by EIA covered multiple BEA categories, a detailed I-O table for the energy type was utilized as an allocation reference. For example, EIA reports the amount of aggregate biomass energy used by pulp and paper mills mainly in the form of black liquor, which is a by-product of paper production process, while BEA distinguishes pulp mills and paper mills as a commodity. In this case, the production value (in producer's price) was used as the allocation factor.
- When estimating energy flows by end-use categories per energy types in the previous step, feedstock energy use was estimated and subtracted from the energy flow information derived from I-O data. For example, the carbon black manufacturing processes use petroleum as a feedstock, not for energy. Therefore, if the entire petroleum flow to carbon black production was counted as energy consumption, the embodied energy of carbon black would be overestimated. In this case, only feedstock petroleum used in carbon black production was subtracted from the petroleum flow.
- Estimates developed using the above approach and CEDA 3.0 were cross-checked with other literature and statistics. CEDA results were also sorted in decreasing order and the top 30 categories were checked for abnormalities. No abnormalities were identified in the data used in the 2020 Vision Relative Ranking Analysis.

In order to include renewable energy in the analysis, explicit choices were made regarding the point of energy "consumption". For fossil fuels and biomass, it was assumed that energy consumption occurs at the point of combustion. For renewable energy, the point of combustion cannot be used as a reference. For example, hydropower uses the potential energy of water. For hydropower and wind power, electric power generation at the power plant was considered the point of energy consumption. For nuclear power, the nuclear power plant was considered as the point of consumption.

Energy use was estimated for the three system perspectives. For the full CEDA 3.0 energy use data incorporated in the multi-factor analysis, please see the spreadsheet, "2020 Vision Multi-Factor Scoring_May09.xls".

Applying the Vector Approach to Ranking

Upon completion of the analysis of individual environmental aspects, materials, products, and services were ranked across all aspects using the vector approach. The 480 materials, products, and services were ranked within criteria using statistical measures, and statistical values were combined across the 17 criteria using vector analysis. Though the bulk of criteria are the 13 categories of environmental impact, all criteria were considered equal and given the same weight in the vector analysis.

Specifically, the following steps were employed to analyze the 480 materials, products, and services using the vector analysis approach:

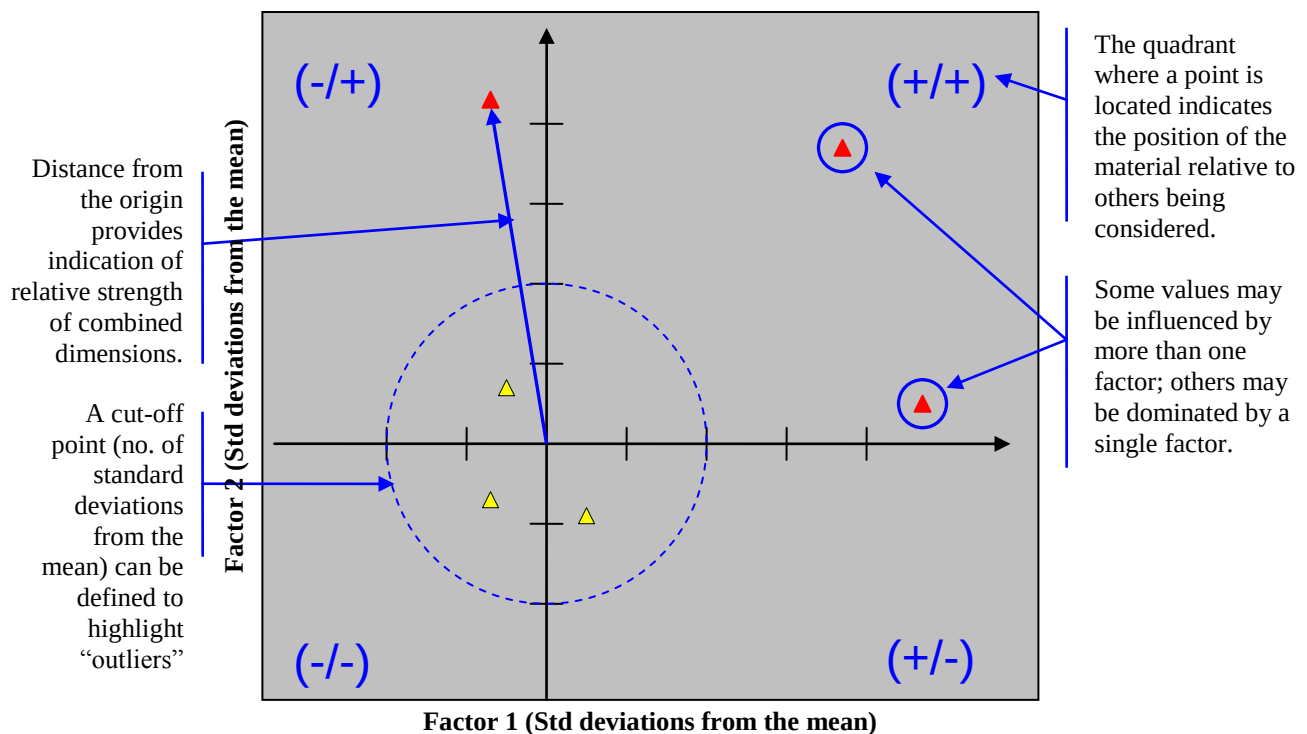
- Data were compiled for each of the 480 materials, products, and services, and for each criterion of environmental impact, resource use, and waste, as described in the previous section.

- The average (mean value) for each criterion was computed and subtracted from the criterion value for each of the 480 materials, products, and services. This approach “mean-centered” the criterion values and, as such, addressed the potential that criteria with large absolute magnitude would dominate the overall vector magnitude.
- The standard deviation for each criterion was calculated and the mean-centered values were normalized by the standard deviation. This approach addressed the potential that criteria with large variation would dominate the overall vector magnitude. This was particularly important given the significant differences in units used for different criteria and enabled the criteria to be compared on a dimensionless basis.

The number of standard deviations from the mean was “plotted” on different axes corresponding to each of the different criteria, producing two pieces of information: 1) vector magnitude and 2) direction of vector. The vector *magnitude* - *distance from the origin or mean* - indicates the degree to which the material, product, or service is an “outlier,” or how much it deviates from the mean relative to all materials, products, and services being measured. The *direction* of the vector is an indicator of the criterion/criteria that has/have the greatest effect on magnitude.

Figure 5 presents a graphical representation of the concept along two dimensions (two criteria). The mathematical rules that apply to two dimensions can be extrapolated to the number of dimensions of interest.

Figure 5
Graphical Representation of Vector Analysis Approach



Supplemental Analyses

In addition to the core relative ranking analysis described above, several supplemental analyses were conducted to assess the functioning of the vector analysis approach, test the sensitivity of the analysis to different assumptions, and help interpret the findings. These supplemental analyses are described in this section. Implications of these supplemental analyses are discussed along with the overall findings and conclusions in the sections that follow.

Analysis of Criteria Distributions and Correlation

The relative ranking analysis using a vector approach does not involve weighting individual criteria. Because the analysis compares a measure of outlier strength across criteria, the influence of individual criteria will depend on the distribution of values among the commodities within that criterion. F-tests were performed to compare the distributions of the mean-centered values used to calculate vector magnitudes and rank materials, products, and services. All of the distributions were statistically equivalent, with the exception of the distribution for the water use criterion.

Observations of the distributions of mean-centered values indicated that the Electric Services category has a significant dampening effect on certain criteria. To test this observation, the analysis was performed without the Electric Services category. As a result, it was determined that the dominance of the electric services industry within the water use criterion accounts for the deviation between the distribution of this criterion from the rest. This finding explains the limited distribution of mean-centered values and suggests that water use criterion has less influence on the rankings relative to other criteria. When Electric Services were removed from the analysis, the water use criterion was indicated as a driver for agricultural materials and products based on the direct impacts/resource use/waste perspective. Water use was also indicated as a driver across a wide range of materials, products, and services from the intermediate and final consumption perspectives. Removal of Electric Services from the analysis did not change the correlation among the other criteria, though this approach did result in minor changes to the rankings.

The results of the individual criterion analyses are not normally distributed. To evaluate the effect of the non-normal distributions, individual criteria output was log transformed and the ranking analysis was conducted using the transformed data. When the transformed data was analyzed using the direct impact/resource use/waste perspective, two factors tended to dominate the analysis: abiotic depletion (ADP) and land use/land competition (LUC). The ADP and LUC distributions are highly skewed because of the limited coverage of the materials, products, and services by these criteria for the direct impact/resource use/waste perspective. When the data were transformed, the distributions of the criteria other than ADP and LUC tended to flatten out, lessening their influence compared to the original approach. The influence of log transformation was further evaluated using the final consumption perspective. The rankings based on the log transformed data differed only slightly from the rankings produced by the original analysis for this perspective.

The nature of the vector analysis is such that each criterion added to the analysis will increase the vector magnitude. Thus, the degree to which individual criteria (e.g., freshwater aquatic toxicity, terrestrial ecotoxicity) pertain to a similar environmental impact category (e.g., ecological

toxicity) could tend to increase the influence of that category on the overall analysis. An analysis was conducted to assess the potential effect of the correlation among criteria on the relative rankings. Table 1 summarizes the results of this analysis.

The analysis suggests that those materials, products, and services that rank high on one criterion will rank high on other, correlated criteria, which will affect the overall rankings. Because the workgroup is interested in all of the environmental issues represented by the factors, this finding does not detract from the 2020 Vision Relative Ranking Analysis. The effect of correlation among criteria should be taken into account when interpreting the results.

Table 1
Criteria Groupings Exhibiting Statistically Significant Correlation
By System Perspective

Direct Impact/Use/Waste Perspective	Intermediate Consumption Perspective	Final Consumption Perspective
• GWP-MAETP-FSETP-POCP-AP-WU-EU • FAETP-TETP	• GWP-MAETP-FSETP-POCP-AP-WU-EU • FAETP-TETP	• GWP-HTP-MAETP-FSETP-POCP-AP • GWP-MAETP-FSETP-AP-WU-EU • ODP-HTP-MSETP • ADP-MW • GWP-EP-HTP-POCP

Sensitivity Analyses

In addition to the core relative ranking analysis presented herein, the workgroup evaluated the following variations on the model to test its sensitivity to alternative assumptions:

- Market trends – the relative output of materials, products, and services included in the analysis reflects market conditions as they existed in 1998. To the extent that the relative output of materials, products, and services has changed, the analysis may under- or over-represent the relative impacts, resource use, and waste associated with different materials, products, and services. Table 2 identifies those industries that have undergone the most significant growth and those that have undergone the most significant decline relative to GDP since 1998. These rates of growth and decline were factored into the final consumption perspective to evaluate the effect on the rankings. It was determined that the rankings were sensitive to the relatively high rate of growth of the “information services” industry and the relatively high rate of decline in the “photographic and photocopying equipment manufacturing” industry. The implications of these findings are discussed in the findings and conclusions sections below.

Table 2
Industries Experiencing the Most Significant Growth or Decline Since 1998

%Growth/Decline*	Industry
Industries Experiencing Most Significant Growth	
744%	Information services
532%	Electronic computer manufacturing
325%	Semiconductors and related device manufacturing
254%	Environmental and other technical consulting services
216%	Securities, commodity contracts, investments
193%	Copper wire, except mechanical, drawing
181%	Management consulting services
173%	Irradiation apparatus manufacturing
166%	Other computer related services, including facilities management
164%	All other miscellaneous professional and technical services
Industries Experiencing Most Significant Decline	
-64%	Accessories and other apparel manufacturing
-66%	Leather and hide tanning and finishing
-68%	Electron tube manufacturing
-68%	Other apparel knitting mills
-68%	Photographic and photocopying equipment manufacturing
-69%	Software reproducing
-70%	Secondary processing of copper
-71%	Manufactured home, mobile home, manufacturing
-71%	Primary smelting and refining of copper
-79%	Tobacco stemming and redrying

* Based on 2000 quantity index, 1998-2007

Source: Bureau of Economic Analysis

- Abiotic depletion and land use criteria excluded – given the limitations of the abiotic depletion and land use criteria (e.g., crude petroleum, agricultural commodities), the analysis was run by excluding each criterion individually and by excluding both criteria. While this variation had some influence on the ranking of criteria, the influence was modest – some materials, products, and services shifted in rank, but there was little change in the top 20-ranked materials, products, and services within the different perspectives. It was determined that further development of these criteria would be encouraged by retaining them in the analysis.
- Normalized environmental impacts – the 13 environmental impacts categories were “normalized” by dividing the vector magnitude by the number of categories, and the results were included in a vector analysis with the material use, material waste, water use, and energy use criteria (total of 5 criteria). Using this approach, the material use criterion dominated the analysis and obscured the deeper insights available by treating all criteria equally.
- Maximum environmental impact only – as another approach to creating a single environmental impact value for comparison to the other four resource use and waste criteria, only the maximum value within the 13 categories was used in the multi-factor analysis. This variation affected the relative rankings of materials, products, and

services, though it tended to shift the same materials, products, and services already ranked highest, rather than elevate new materials, products, and services to the highest rankings. Upon review the Workgroup concluded that each of the criteria identified for the analysis represented an important environmental issue and that the original analysis would provide richer detail to support the objectives of the 2020 Relative Ranking Analysis.

Other Interpretive Analyses

In support of the 2020 Vision relative ranking objectives, two additional analyses were conducted to demonstrate the manner in which the three system perspectives and use of multiple criteria affect the relative rankings:

- Criteria layering – A single criterion global warming potential (GWP) was used to demonstrate how the rankings change when criteria are added. The results of the criteria layering analysis are summarized in Appendix A and are discussed in the findings and conclusions section below.
- System perspectives – A single criterion, GWP, was used to demonstrate how the ranks of materials, products, and services differ based on system perspectives. The results of the system perspectives analysis are summarized in Appendix B and are discussed in the findings and conclusions sections below.

The spreadsheet, “2020 Vision Multi-Factor Scoring_May09.xls” presents the full vector analysis with mean, standard deviation, and other manipulations referenced above.

Summary of Findings

This section presents a brief summary of the results of the 2020 Vision Relative Ranking Analysis when examining individual criteria separately and all 17 criteria together and across all system perspectives.

Observations Related to Individual Criteria

Appendix A presents the results of the individual criterion analysis. The 17 tables in Appendix A show the 20 highest ranked materials products and services based on each individual criterion for the three system perspectives. Different criteria tend to rank high different materials, products, and services. High-level findings associated with each criterion and groups of criteria are summarized below.

- The abiotic depletion (ADP) criterion tends to rank high non-renewable organic materials (e.g., crude oil, coal) and intermediate products and services associated with industries that consume these materials as feedstocks or fuel (e.g., petroleum refining, electric services). As noted above, this criterion is limited in its coverage. Notably missing are the rare metals which are in greater demand as technology advances.
- The land use/competition (LUC) criterion tends to rank high agricultural products (e.g., meat animals, dairy farm products, food grains) and associated products and services

(e.g., meat packing plants, eating and drinking places, fluid milk). As noted above, this criterion has limitations.

- The global warming potential (GWP), acidification potential (AP) and photochemical oxidation potential (POCP) criteria tend to rank high similar materials, products and services, primarily petroleum materials and products, electric services, and energy-intensive products and services such as blast furnaces and steel mills, motor vehicle and passenger car bodies, and retail trade. However, GWP tends to also rank high agriculture-related materials, products, and services as well (e.g., meat animals, feed grains, meat packing plants, and eating and drinking places).
- The ozone depletion potential (ODP) criterion tends to rank high products related to petroleum (e.g., industrial inorganic and organic chemicals, synthetic rubber, plastic materials and resins), energy-intensive materials and products (e.g., primary aluminum, motor vehicle and passenger car bodies), and products and services that tend to be consolidate a widely dispersed range of intermediate products and services (e.g., eating and drinking places, buildings, and hospitals).
- The human toxicity potential (HTP) and marine sedimental aquatic toxicity potential (MSETP) criteria tends to rank high similar materials, products, and services, including pulp and paper mills, chemicals, and primary metals as well as products associated with construction and development, retail and wholesale trade, and hospitals.
- The freshwater aquatic ecotoxicity toxicity potential (FAETP) and terrestrial ecotoxicity potential (TETP) criteria tend to rank high the similar materials, products, and services, primarily those related to agriculture such as feed grains, cotton, paper and paperboard, textiles, and apparel. The eutrophication potential (EP) criterion tends to rank high the same materials, products, and services as the FAETP and TETP criteria as well as petroleum-related and energy-intensive materials, products and services such as petroleum refining, blast furnaces and steel mills, and retail trade.
- The material use (MU) criterion tends to rank high construction and development-related materials, products and services such as sand and gravel, new office, industrial, and commercial buildings construction, and real estate agents, managers, operators, and lessors) and high volume-related materials, products and services (e.g., coal, feed grains, and eating and drinking places).
- The material waste (MW) criterion tends to rank high a very diverse range of materials, products and services such as coal, lime, forestry products, industrial inorganic and organic chemicals, plastic materials and resins, new residential 1-unit structures, and hospitals.
- The water use (WU) criterion tends to rank high agriculture-related materials products and services such as feed grains and eating and drinking places, in addition to electric services.
- The energy use (EU) criterion ranks high very few materials, primarily ranking high intermediate life cycle stages (e.g., blast furnaces and steel mills), transportation-related services (e.g., air transportation and trucking and courier services), and a range of services (e.g., retail trade, eating and drinking places, and hospitals).

- Electric services is the highest ranked commodity for GWP, POCP, HTP, MAETP, FSETP, AP, EP, and EU in all system perspectives. For LUC, ODP, FAETP, MSETP, and TETP, electric services does not rank within the highest ranks (defined as top 20). And for ADP, MU and MW, electric services ranks within the highest ranks, but not for all system perspective.

Table 3. Direct Impact/Resource Use/Waste Perspective

Material, Product, or Service	Total Vector Magnitude	Criteria Contributing Significantly to Vector Magnitude (> 2 standard deviations above the mean)*																
		Environmental Impact													MU	MW	WU	EU
		ADP	LUC	GWP	ODP	HTP	FAETP	MAETP	TETP	FSETP	MSETP	POCP	AP	EP				
Electric services (utilities)	56.30			●		●		●		●		●	●	●			●	●
Cotton	28.85						●		●					●				
Industrial inorganic and organic chemicals	22.76				●	●					●					●		
Crude petroleum and natural gas	19.17	●		●								●						
Coal	19.06	●														●	●	
Meat animals	16.39		●															
Paper and paperboard mills	14.57					●					●							
Petroleum refining	14.45															●	●	
Feed grains	13.43		●				●		●					●		●		
New residential 1 unit structures, nonfarm	11.49															●		
Pulp mills	11.18					●					●							
Photographic equipment and supplies	10.45					●					●							
Food grains	10.15		●											●				
Dimension, crushed and broken stone	9.98															●		
Natural gas distribution	9.09															●	●	
Miscellaneous crops	8.84						●		●					●				
Sand and gravel	8.79															●		
Primary aluminum	8.65				●	●		●		●	●							
Dairy farm products	7.92		●															
Poultry and eggs	7.10		●															

* Shaded cells indicate situations where a single criterion dominated the vector magnitude; for environmental impacts, the dominant criterion is highlighted.

Table 4. Intermediate Consumption Perspective

Material, Product, or Service	Total Vector Magnitude	Criteria Contributing Significantly to Vector Magnitude (> 2 standard deviations above the mean)*																
		Environmental Impact													MU	MW	WU	EU
		ADP	LUC	GWP	ODP	HTP	FAETP	MAETP	TETP	FSETP	MSETP	POCP	AP	EP				
Electric services (utilities)	52.21	●		●		●		●		●		●	●	●	●	●	●	●
Cotton	21.37						●		●					●				
Industrial inorganic and organic chemicals	21.32				●	●					●	●		●		●		
Crude petroleum and natural gas	18.37	●		●								●	●	●				
Petroleum refining	15.62	●		●								●	●	●	●	●		
Meat animals	15.20		●				●		●					●				
Paper and paperboard mills	15.07					●					●							
New residential 1 unit structures, nonfarm	14.96			●	●	●				●	●	●			●			
Coal	14.71	●													●	●		
Broadwoven fabric mills and fabric finishing plants	14.67						●		●					●				
Meat packing plants	11.57		●				●		●					●				
Motor vehicles and passenger car bodies	11.23			●	●	●		●		●	●	●		●				●
Apparel made from purchased materials	10.30						●		●					●				
Natural gas distribution	10.26	●													●	●		
Feed grains	9.84		●				●		●					●				
Eating and drinking places	9.21		●	●			●		●			●		●				
Blast furnaces and steel mills	8.79			●		●						●				●		●
Real estate agents, managers, operators, and lessors	8.31			●		●						●			●			
Wholesale trade	8.14			●	●	●					●	●						●
Primary aluminum	8.02				●	●		●		●	●							

* Shaded cells indicate situations where a single criterion dominated the vector magnitude; for environmental impacts, the dominant criterion is highlighted.

Table 5. Final Consumption Perspective

Material, Product, or Service	Total Vector Magnitude	Criteria Contributing Significantly to Vector Magnitude (> 2 standard deviations above the mean)*																
		Environmental Impact													MU	MW	WU	EU
		ADP	LUC	GWP	ODP	HTP	FAETP	MAETP	TETP	FSETP	MSETP	POCP	AP	EP				
Electric services (utilities)	54.24	●		●		●		●		●		●	●	●	●	●	●	●
Apparel made from purchased materials	27.43				●	●	●		●		●			●				
Petroleum refining	22.82	●		●	●							●	●	●	●	●		
Motor vehicles and passenger car bodies	22.51	●		●	●	●	●	●	●	●	●	●	●	●		●		●
Eating and drinking places	21.52		●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Retail trade, except eating and drinking	17.26	●		●	●	●		●		●	●	●	●	●	●	●	●	●
Meat packing plants	16.46		●				●		●					●				
New residential 1 unit structures, nonfarm	14.71			●	●	●					●	●		●	●	●		
Hospitals	13.54			●	●	●			●	●	●	●		●		●		●
New highways, bridges, and other horizontal construction	12.40					●						●			●			
Owner-occupied dwellings	11.75			●	●	●					●	●		●	●			
Natural gas distribution	11.07	●														●		
Other new construction	10.93			●	●	●					●	●			●			
Photographic equipment and supplies	9.31					●				●								
Wholesale trade	7.49				●	●					●	●						
New office, industrial and commercial buildings construction	7.46				●	●					●	●			●			
Poultry slaughtering and processing	7.17		●															
Real estate agents, managers, operators, and lessors	7.05				●	●						●			●			
Food preparations, n.e.c.	6.26						●		●					●				
Fluid milk	5.81		●															

* Shaded cells indicate situations where a single criterion dominated the vector magnitude; for environmental impacts, the dominant criterion is highlighted.

**Table 6. Summary of Top-Ranked Materials, Products, and Services
2020 Vision Relative Ranking Analysis**

Material, Product, or Service		Final Rank			Criteria Contributing Significantly to Rank (OOO = Direct Impact/Resource Use/Waste, Intermediate Consumption, Final Consumption)																
					Environmental Impact													MU	MW	WU	EU
		DI	IC	FC	ADP	LUC	GWP	ODP	HTP	FAETP	MAETP	TETP	FSETP	MSETP	POCP	AP	EP				
Food Products & Services	Dairy farm products	19	---	---	OOO	●OO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO
	Poultry and eggs	20	---	---	OOO	●OO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO
	Meat animals	6	6	---	OOO	●●O	OOO	OOO	OOO	●●O	OOO	●●O	OOO	OOO	OOO	OOO	●●O	OOO	OOO	OOO	OOO
	Food grains	13	---	---	OOO	●OO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	●OO	OOO	OOO	OOO	OOO
	Feed grains	9	15	---	●●O	●●O	OOO	OOO	OOO	●●O	OOO	●●O	OOO	OOO	OOO	OOO	●●O	●●O	OOO	OOO	OOO
	Miscellaneous crops	16	---	---	OOO	OOO	OOO	OOO	OOO	●OO	OOO	●OO	OOO	OOO	OOO	OOO	●OO	OOO	OOO	OOO	OOO
	Meat packing plants	---	11	7	OOO	●●●	OOO	OOO	OOO	●●●	OOO	●●●	OOO	OOO	OOO	OOO	●●	OOO	OOO	OOO	OOO
	Poultry slaughtering and processing	---	---	17	OOO	OO●	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO
	Eating and drinking places	---	16	5	OOO	●●●	●●●	OO●	OO●	●●●	OO●	●●●	OO●	OO●	●●●	OO●	●●●	OO●	OO●	OOO	OO●
	Food preparations, n.e.c.	---	---	19	OOO	OOO	OOO	OOO	OOO	OO●	OOO	OO●	OOO	OOO	OOO	OOO	OO●	OOO	OOO	OOO	OOO
	Fluid milk	---	---	20	OOO	OO●	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO
Textiles	Cotton	2	2	---	OOO	OOO	OOO	OOO	OOO	●●O	OOO	●●O	OOO	OOO	OOO	OOO	●●O	OOO	OOO	OOO	OOO
	Apparel made from purchased materials	---	13	2	OOO	OOO	OOO	OO●	OO●	●●●	OOO	●●●	OOO	OO●	OOO	OOO	●●●	OOO	OOO	OOO	OOO
	Broadwoven fabric mills and fabric finishing plants	---	10	---	OOO	OOO	OOO	OOO	OOO	●●O	OOO	●●O	OOO	OOO	OOO	OOO	●●O	OOO	OOO	OOO	OOO
Nonrenewable Organics	Coal	5	9	---	●●O	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	●●●	●●●	OOO	OOO
	Crude petroleum and natural gas	4	4	---	●●O	OOO	●●O	OOO	OOO	OOO	OOO	OOO	OOO	OOO	●●O	●●O	●●O	OOO	OOO	OOO	OOO
	Industrial inorganic and organic chemicals	3	3	---	OOO	OOO	OOO	●●O	●●O	OOO	OOO	OOO	OOO	●●O	●●O	OOO	●●O	OOO	●●O	OOO	OOO
	Petroleum refining	8	5	3	●●●	OOO	●●●	OO●	OOO	OOO	OOO	OOO	OOO	OOO	●●O	●●O	●●O	●●●	●●●	OOO	OOO
	Electric services (utilities)	1	1	1	●●●	OOO	●●●	OOO	●●●	OOO	●●●	OO●	●●●	OOO	●●O	●●O	●●O	●●●	●●●	●●●	●●●
	Natural gas distribution	15	14	12	●●●	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	OOO	●●O	●●O	OOO	OOO
Mining & Metals	Blast furnaces and steel mills	---	17	---	OOO	OOO	●●O	OOO	●●O	OOO	OOO	OOO	OOO	OOO	●●O	OOO	OOO	OOO	●●O	OOO	●●O
	Primary aluminum	18	20	---	OOO	OOO	OOO	●●O	●●O	OOO	●●O	OOO	●●O	●●O	OOO	OOO	OOO	OOO	OOO	OOO	OOO
	Motor vehicles and passenger car bodies	---	12	4	OO●	OOO	●●●	●●●	●●●	OO●	●●●	OO●	●●●	●●●	●●O	●●O	●●O	OOO	●●O	OOO	●●●

**Table 6 (continued). Summary of Top-Ranked Materials, Products, and Services
2020 Vision Relative Ranking Analysis**

Material, Product, or Service		Final Ranking			Criteria Contributing Significantly to Rank (○○○ = Direct Impact/Resource Use/Waste, Intermediate Consumption, Final Consumption)																
					Environmental Impact														MU	MW	WU
		DI	IC	FC	ADP	LUC	GWP	ODP	HTP	FAETP	MAETP	TETP	FSETP	MSETP	POCP	AP	EP				
Construction & Development	Dimension, crushed and broken stone	14	---	---	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	●○○	○○○	○○○	○○○
	Sand and gravel	17	---	---	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	●○○	○○○	○○○	○○○
	New residential 1 unit structures, nonfarm	10	8	8	○○○	○○○	○●●	○●●	○●●	○○○	○○○	○○○	○●○	○●●	○●●	○○○	○○●	●●●	○○●	○○○	○○○
	Other new construction	---	---	13	○○○	○○○	○●●	○●●	○●●	○○○	○○○	○○○	○○○	○○●	○●●	○○○	○○○	○○●	○○○	○○○	○○○
	Owner-occupied dwellings	---	---	11	○○○	○○○	○○○	○●●	○●●	○○○	○○○	○○○	○○○	○○●	○●●	○○○	○○○	○○●	○○○	○○○	○○○
	New highways, bridges, and other horizontal construction	---	---	10	○○○	○○○	○○○	○○○	○●●	○○○	○○○	○○○	○○○	○○○	○○●	○○○	○○○	○○●	○○○	○○○	○○○
	New office, industrial and commercial buildings construction	---	---	16	○○○	○○○	○○○	○●●	○●●	○○○	○○○	○○○	○○○	○○●	○●●	○○○	○○○	○○●	○○○	○○○	○○○
Forest	Pulp mills	11	---	---	○○○	○○○	○○○	○○○	●○○	○○○	○○○	○○○	○○○	●○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○
	Paper and paperboard mills	7	7	---	○○○	○○○	○○○	○○○	●●○	○○○	○○○	○○○	○○○	●●○	○○○	○○○	○○○	○○○	○○○	○○○	○○○
Other Products & Services	Computer and data processing services; including own-account software ⁽¹⁾	---	---	---	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○○	○○●	○○○	○○○	○○○	○○○	○○○	○○○	○○○
	Photographic equipment and supplies ⁽²⁾	12	---	14	○○○	○○○	○○○	○○○	●●○	○○○	○○○	○○○	○○○	●●○	○○○	○○○	○○○	○○○	○○○	○○○	○○○
	Wholesale trade	---	19	15	○○○	○○○	○●○	○●●	○●●	○○○	○○○	○○○	○○○	○○●	○●●	○○○	○○○	○○○	○○○	○○○	○●○
	Retail trade, except eating and drinking	---	---	6	○○●	○○○	○○●	○○●	○○●	○○○	○○●	○○○	○○●	○○●	○○●	○○●	○○●	○○●	○○●	○○●	○○●
	Hospitals	---	---	9	○○○	○○○	○○●	○○●	○○●	○○○	○○○	○○●	○○●	○○●	○○●	○○○	○○○	○○○	○○●	○○○	○○●
	Real estate agents, managers, operators, and lessors	---	18	18	○○○	○○○	○●●	○○○	○●●	○○○	○○○	○○○	○○○	○○○	○●●	○○○	○○○	○●●	○○○	○○○	○○○

Notes: (1) The supplemental markets trends analysis suggests that if relative output were adjusted from 1998 to 2007 levels, the “computer and data processing services” category would rank as high as second from the final consumption perspective.

(2) The supplemental market trends analysis suggests that if relative output were adjusted from 1998 to 2007 levels, the “photographic equipment and supplies” category would be ranked below the top 20 from the final consumption perspective.

Key: System perspectives:

DI = Direct impact/use/waste perspective

IC = Intermediate Consumption perspective

FC = Final Consumption perspective

Rank:

--- = Ranked below top 20

Symbols/Drivers:

● ≥ 2 standard deviations from mean

○ < 2 standard deviations from mean

Drivers:

ADP = Abiotic Depletion Potential

LUC = Land Use/Land Competition

GWP = Global Warming Potential

ODP = Ozone Depletion Potential

HTP = Human Toxicity Potential

FAETP = Freshwater Aquatic Ecotox. Potential

MAETP = Marine Aquatic Ecotox. Potential

TETP = Terrestrial Ecotoxicity Potential

FSETP = Freshwater Sedimental Ecotoxicity Potential

MSETP = Marine Sedimental Ecotoxicity Potential

POCP = Photochemical Oxidation Potential

AP = Acidification Potential

EP = Eutrophication Potential

MU = Material Use

MW = Material Waste

WU = Water Use

EU = Energy Use

Observations Related to Perspectives

Tables 3 through 5 present the top 20 highest ranked materials, products, and services when ranked across all criteria. Each table presents the top 20 in rank order from one of the three system perspectives, their final vector magnitude, and the criteria that had the greatest influence on their vector magnitude and therefore relative rank. Appendix B presents results when looking at a single criterion, specifically the Global Warming Potential criterion, across the three system perspectives. A key for reading the tables follows Table 6. In general, the three system perspectives, direct impact/resource use/waste, intermediate consumption, and final consumption tend to highlight different sets of materials, products, and services according to their stage in the supply chain. Further, all criteria significantly contribute to the vector magnitude of the highest ranked materials, products and services. Additional high-level findings from Tables 3 – 5 and Appendix B include:

- The direct impact/resource use/waste perspective tends to rank high raw materials and less refined products such as coal, cotton, primary aluminum, and paper and paperboard mills. Most criteria significantly contribute to the vector magnitude of two to three of the highest ranking materials, products and services. The material use criterion significantly contributes to the largest number of materials, products and services (i.e., seven). Most of the top 20 materials, products or services have three or less criteria contributing significantly to their vector magnitude. Electric services has the highest number of criteria (i.e., nine) contributing significantly.
- The intermediate consumption perspective tends to rank high a mix of raw materials (e.g., meat animals and coal), material processing and manufacturing stages (e.g., industrial inorganic and organic chemicals and broadwoven fabric mills and fabric finishing plants), “finished” products (e.g., apparel made from purchased materials), and services (e.g., eating and drinking places). On average, each criterion significantly contributes to the vector magnitude of five of the highest ranking materials, products and services. The eutrophication potential criterion significantly contributes to the largest number of materials, products and services (i.e., 12). Most of the top 20 materials, products or services have, on average, five criteria contributing significantly to their vector magnitude. Electric services has the highest number of criteria (i.e., 12) and feed grains the second highest number (i.e., 9) contributing significantly.
- The final consumption perspective tends to rank high “finished” products (e.g., motor vehicle and passenger car bodies) and services (e.g., eating and drinking places). No raw materials make the highest ranks. On average, each criterion significantly contributes to the vector magnitude of eight of the highest ranking materials, products and services. The human toxicity potential criterion significantly contributes to the largest number of materials, products and services (i.e., 14). Most of the top 20 materials, products or services have, on average, six criteria contributing significantly to their vector magnitude. Eating and drinking places has the highest number of criteria (i.e., 15) contributing significantly, while motor vehicle and passenger car bodies and retail trade have the second highest number (i.e., 14).
- Each perspective highlights potentially significant problematic materials, products, or services that the other perspectives missed. For example, raw materials such as coal or cotton are ranked highly based on the direct impact/resource use/waste perspective, but

their rankings decrease dramatically as the perspective shifts toward final consumption. This reflects coal and cotton not being consumed directly, for the most part, by households or government but, rather, used to produce products that are consumed. The impacts and other aspects associated with the extraction of coal or harvesting of cotton are “passed through” to downstream products based on the LCA methodology. Products such as “new office buildings” exhibit the opposite trend and reflect the fact that such products are an amalgamation of raw materials and intermediate products.

- The system perspectives analysis summarized in Appendix B further demonstrates the value of considering all three system perspectives, even when examining a single criterion. Using GWP as an example, the direct impacts/resource use/waste perspective ranks high raw materials and early processes such as feed grains and blast furnaces and steel mills. However, when looking at embedded GWP, final products and services such as hospitals, meat packing plants, and automotive repair shops and services tend to rank high.

Observations Related Layering Criteria

Appendix C presents the results of the criteria layering analysis performed to provide insights regarding the merits of integrating criteria. For the criteria layering analysis, results for a single criterion, global warming potential (GWP), were compared to the results when all environmental impact criteria were used, and then to the results when all seventeen criteria were used. For GWP from the final consumption perspective, air transportation and meat packing plants ranked high and were close in terms of their potential life cycle global warming impacts. Addressing either from a life cycle perspective would achieve important GHG reductions. However, when the remaining environmental impact criteria are included, the rank of meat packing plants rises significantly while the rank of air transportation falls. When the resource use and material waste criteria are added, meat packing plants maintain their relatively high ranking and air transportation rises, but remains significantly lower than meat packing plants. Thus, if meat packing plants are addressed from a life cycle perspective, significant benefits potentially could be realized related to land use, freshwater aquatic ecotoxicity, photochemical oxidation, terrestrial ecotoxicity and eutrophication, in addition to global warming. Addressing air transportation, on the other hand, primarily provides only energy use and global warming benefits.

Observations Related to Full Relative Ranking Analysis

Table 6 compiles the information from Tables 3 through 5, listing all materials, products, and services that were ranked within the top 20 from the three system perspectives. The table presents the individual materials, products and services grouped into seven broad categories: construction and development, food products and services, forestry, metals, nonrenewable organics, textiles, and other products and services. They are grouped in a manner to depict crude direct relationships (e.g., feed grains, meat animals, meat packing plants, eating and drinking places). For each material, product and service, the table shows its final rank within the top 20 for each perspective, as well as the criteria contributing significantly to its high ranking. “Computer and Data Processing Services” was added to the table based on the results of the market trends analysis due to its profound growth. Also, “Photographic Equipment and

Supplies” is footnoted to highlight their marked decline since 1998. Compiling the information from across Tables 3 -5 reveals the following high-level findings:

- A total of 38 materials, products and services are listed in Table 6. Eighteen are in the highest ranks only for one perspective: seven for only the direct perspective, most of which are raw materials; two for only the intermediate perspective, both are from the processing stage; and nine for only the final perspective, all of which are products and services. Fifteen materials, products and services are in the highest ranks for two perspectives: eight for both the direct and intermediate perspectives, all are either raw materials or processing stages; six for both the intermediate and final consumption perspectives, all products and services; and one for both the direct and final consumption perspectives. Four materials, products and services are in the highest ranks for all perspectives – petroleum refining, electric services, natural gas distribution and new residential 1 unit structures (nonfarm).
- Almost half of the top-ranked materials, products and services are directly related to food and construction and development, although it is recognized that most of the 38 materials, products and services are likely connected.
- For the Food Products and Services, Nonrenewable Organics, and Mining and Metals groupings, almost all criteria significantly contribute. Forestry has the fewest at two criteria contributing significantly, which are also the two criteria that contribute significantly to the highest ranks in all seven groupings – no criterion contributes significantly to all 38 materials, products and services. Eating and drinking places have the highest number of criteria significantly contributing (at 15), followed by motor vehicles and passenger car bodies (at 14), retail trade (at 14), and electric services (at 13).
- Connections between highly ranked, closely-linked raw materials and finished products (e.g., cotton and apparel) demonstrate the interaction of criteria and perspectives reflected in the use of the LCA methodology. Such connections reflect the approach whereby significant impacts, resource use, or waste at earlier stages in a supply chain are passed through to downstream products. When the raw materials and downstream products are closely linked, the impacts, resource use, or waste associated with early stages in the supply chain will also affect the rankings of intermediate and final consumption perspectives.
- As for the criteria, human toxicity potential (HTP) and eutrophication potential (EP) significantly contribute to the greatest number of highest ranked materials, products and services (19 of them each). They are followed by the marine sediment ecotoxicity potential (MSETP), photochemical oxidation potential (POCP), and materials use (MU) criteria contributing significantly, 16, 16, and 15 materials, products and services, respectively. The marine aquatic ecotoxicity potential (MAETP) criterion is the least influential criterion within the highest ranks, only affecting five of the 38 materials, products and services. The freshwater aquatic ecotoxicity potential (FAETP) and terrestrial ecotoxicity potential (TETP) criteria primarily influence food and textile-related materials, products and services (e.g., food grains and cotton). The land use criterion strongly influences food-related materials, products and services (e.g., food grains, meat animals).

- The material use criterion primarily influences the ranking of construction- and petroleum-related materials and products as well as products and services that tend to consolidate a variety of intermediate products and services at the point of final consumption, such as eating and drinking places, buildings, and retail trade.
- The material waste criterion primarily influences non-renewable organic-related materials, product and services, and energy-intensive intermediate and final products (e.g., blast furnaces and steel mills and motor vehicle and passenger car bodies), and services that consume non-durable goods, such as retail trade, eating and drinking places, and hospitals.
- The water use criterion has little affect on the rankings, most likely due to the dominance of the electric services industry in this area.
- The energy use criterion influences energy-intensive intermediate products and final products such as blast mills and steel mills and motor vehicle and passenger car bodies, as well products and services that tend to consolidate a variety of intermediate products and services at the point of final consumption, such as eating and drinking places, retail trade, and hospitals.

Discussion and Conclusions

The 38 highest ranking materials, products and services from the 2020 Vision Relative Ranking Analysis offer a reasonable pool of candidates to be the focus of initial application of materials management strategies. Indeed, the findings of the analysis provide a wealth of information on which to draw when selecting targets and crafting life-cycle strategies. Tables 3 through 6 highlight materials, products, and services where materials management strategies potentially could provide significant benefits across multiple environmental aspects. The tables in Appendices B and C provide insights to help interpret the results of the analysis based on different perspectives and the interaction of different criteria.

Not only do these highest ranking materials, products and services potentially offer significant benefits across multiple environmental aspects if addressed from a life-cycle approach, but also the opportunity to explore different facets of a sustainable approach to materials management given their diversity (e.g., from metals to food, from single-material products to multi-material products and services). Part of the objective of sustainable materials management is to use and reuse resources in the most productive and sustainable manner throughout their life cycles. However, different types of materials will have very different life spans and use/reuse capabilities. For example, metals have the potential to be continually used and reused, thus constantly cycling between the industrial and societal systems once removed from the ecological system. Paper fiber, on the other hand, potentially can be used and reused, but for a limited amount of time as the fibers begin to wear, taking a diminishing circular path between the industrial and societal systems. And food essentially takes a linear or “one-time” path and is returned to the ecological system not long after it was removed. Contained within the highest ranks from the relative ranking analysis are materials and products representing varying life spans and use/reuse capabilities and thus enable the ability to explore developing sustainable materials management strategies in this context.

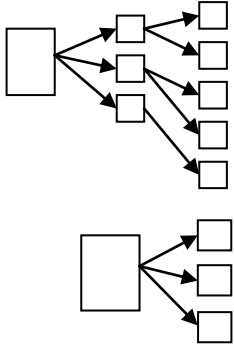
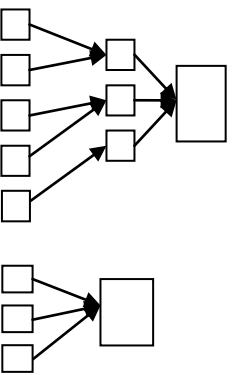
Another way to view the findings of this analysis, and perhaps align them with different demonstration project objectives, is to group the materials, products, and services based on their orientation relative to the three system perspectives and the number and diversity of criteria that may be affected. The 38 materials, products and services can be described as: “upstream confluent” or “downstream confluent” or, alternatively, as “materials-oriented” or “products-oriented.” Table 7 defines these orientations using the terminology of the 2020 Vision Relative Ranking Analysis, describes the implications of these orientations for decisions regarding demonstration project priorities, and identifies materials, products, and services associated with the two orientations that are both highly ranked and address multiple aspects and/or criteria.

Based on these considerations, Table 7 identifies nine materials, products, and services that could provide useful insights for demonstration projects that are intended to explore upstream-confluent or material-oriented strategies. The table identifies twelve materials, products, and services that could provide useful insights for demonstration projects focused on downstream-confluent or product-oriented strategies.

Regardless of orientation, demonstration projects selecting using this approach should be designed to address the entire materials system and exert pressures using a full range of materials management tools (e.g., consumer choice, retail pressure, subsidies/tax policy, etc). Using cotton as an example, the table synthesizes the results of the analysis and suggests that there is a substantial number and range of consumers of intermediate and end products containing cotton. Given the number of individual consumers, a successful consumer-oriented strategy could exert strong pressure to demand change from the cotton growing industry. However, to be effective, such a strategy would need to be broadly focused on the diverse range of consumers. In addition, such a strategy could be used in conjunction with other bold policies, such as a toxics tax.

Conversely, a product-oriented strategy could be narrowly focused on a single end product or service, such as health care services provided by hospitals. Rather than targeting a specific raw material such as cotton, a focus on hospitals would have an effect on a broad range of raw materials and intermediate products and services, with the potential to address a broad range of environmental impacts and resource issues.

Table 7. Material, Product, and Service Orientations Relative to System Perspectives

	System Orientations (Diagram – See Fig. 1)	Definition	2020 Vision Ranking Analysis Characteristics	Implications for Demonstration projects	Materials/Products/Services in Category*
Upstream-confluent or Materials-oriented		Materials, products, and services that embody concentrated environmental impacts, resource use, or waste at an early or intermediate stage in the material system. Materials, products, and services in this category have dispersed downstream applications.	• Ranked high from the direct impact/resource use/waste perspective but relatively low from the intermediate or final consumption perspectives. • Ranked high from the intermediate consumption perspective but relatively low from the final consumption perspective.	• Policies/actions focused on raw material producers or upstream processing stages could be targeted to a well-defined universe. • Policies/actions focused on final or intermediate uses would need to consider a diverse range of uses. • Policies/actions targeting final or intermediate uses could have large cumulative effects on upstream material/product of interest. • Targeting a single or small subset of final or intermediate uses may have little overall effect.	• Coal • Cotton • Crude petroleum and natural gas • Feed grains • Industrial inorganic and organic chemicals • Miscellaneous crops • Paper and paperboard mills • Primary aluminum • Sand and gravel
Downstream-confluent or Product-oriented		Materials, products, and services that accumulate concentrated environmental impacts, resource use, or waste at the point of final or intermediate consumption. Materials, products, and services in this category embody a dispersed range of upstream materials, products, and services.	• Ranked high from the final consumption perspective but relatively low from the direct impact/resource use/waste or intermediate consumption perspectives. • Ranked high from the intermediate consumption perspective but relatively low from the direct impact/resource use/waste perspective.	• Policies/actions focused on a narrow set of final or intermediate products or services could have diverse upstream impacts. • Policies/actions focused on a limited set of final or intermediate products or services may have little overall effect on a specific material. • Policies/actions would need to be predicated on an understanding of the relationship between material/ product of interest and upstream supply chain.	• Apparel made from purchased materials • Eating and drinking places • Fluid milk • Food preparations, n.e.c • Hospitals • Meat packing plants • Motor vehicles and passenger car bodies • Other new construction • Owner-occupied dwellings • Real estate agents, managers, operators, and lessors • Retail trade, except eating and drinking • Wholesale trade

* Items identified in this list include materials, products, and services that were ranked high based on the subject supply chain perspective and based on either more than one environmental aspect or four or more criteria.

In addition to the 21 materials, products, and services identified in Table 7, three products and services rank high regardless of the system perspective and rank high based on either more than one environmental aspect and four or more criteria: electric services (utilities); new residential 1 unit structures, non-farm; and petroleum refining. This suggests that materials management strategies in these areas could involve multiple approaches with wide-ranging effects. However, because they are diverse and far-reaching, it may be difficult to isolate the effects of materials management demonstration projects in these product/service sectors.

The seven groupings presented in Table 6 also offer another view when considering materials, products, and services for demonstration projects. Each of these groupings are ranked highly across multiple perspectives, and like the three products and services noted above, materials management strategies in these areas could involve multiple approaches and impact multiple environmental criteria. For example:

- The mix of highly ranked materials, products, and services within the food products and services grouping suggests the potential for a multi-faceted strategy that could target a range of producers of raw materials, intermediate manufacturers, and final consumers. For example, a strategy focused on meat products could target consumers of meat products, meat packing plants, and feed grain farmers and, thereby, allow the examination of policy and coordination strategies in a variety of contexts. The strategy could focus on environmental impacts relevant to this grouping (e.g., land use, freshwater aquatic ecotoxicity, and eutrophication potential) and water use.
- The textiles grouping offers an opportunity to address highly ranked and closely linked materials, products and services. – cotton, broad woven fabric mills, and apparel This type of close linkage suggests the opportunity for examining a more targeted set of policies and coordination approaches within a well-defined and narrow context. Because there are fewer contextual variables, a focus in this area may lend clearer insights into specific types of policies and coordination strategies.
- Like the food products and services grouping, the nonrenewable organics grouping involves a rich mix of highly ranked raw materials and intermediate and final products. An examination within this sector could cut across consumers and a range of producers. The analysis suggests that a focus in this area could provide opportunity to affect multiple aspects, including environmental impact, energy use, water use and waste.
- Construction and development grouping offers the challenge of developing materials management strategies in the context of very long-lived “products” or infrastructure, and areas often used as a measure of economic performance.

The 2020 Vision Relative Ranking Analysis suggests areas of focus for the future development of LCA methodologies and opportunities for integrating LCA in policy analysis and priority-setting, as well as need for more complete data. For example, the analysis highlights the limitations of criteria such as water use, abiotic depletion, and land use based on land competition. It also points out the insights that could be gained from including criteria such as material use and water use and considering more broadly-defined “consumers” and alternative consumption perspectives, and the challenges that remain in developing methodologies in these areas.

The information generated and the tools created for the 2020 Vision Relative Ranking Analysis provide a starting point for selecting materials, products or services for demonstration projects that can show the value of the materials management approach. And this information generated and these tools created can be further used in developing strategies for these pilots. For example, structural path analysis using the CEDA 3.0 model could provide additional insights into relevant supply chains associated with an area of policy focus. Using structural path analysis, a more detailed understanding of the pathways within a supply-chain network through which environmental impacts, resource use, and waste are accumulated in downstream intermediate and end products can be constructed to help better inform materials management strategies.

On a broader level, this analysis shows the merits of and need for examining the full range of environmental aspects on a life-cycle basis when developing government policies or business decisions. Even when focused on a particular environmental issue, for example climate change, and setting priorities around that issue, this analysis shows that it is possible to target approaches that provide a greater range of benefits while still achieving a particular goal.

Limitations and Uncertainties

The 2020 Vision Relative Ranking Analysis is intended to help identify potential candidate materials, products, and services where materials management policies may have the greatest potential to make a difference across multiple environmental aspects. This is a first attempt at such an analysis. The desire was to produce reasonable choices for materials, products, and services to serve as demonstration projects. The desire was not perfect choices or rankings, but smart choices. Methodological decisions were based on the need for a relative-ranking analysis among the 480 materials, products, and services included in the baseline, rather than an assessment of absolute environmental impact, resource (material, energy, water) use, or waste.

Given its national scope, the 2020 Vision Relative Ranking Analysis employed the concepts and methods of input-output LCA rather than process model LCA. Input-output LCA models can incorporate the entire national economy, whereas process model LCA studies must draw arbitrary boundaries around the analysis to make the studies viable. Economic input-output analysis use monetary flows as a common unit to proxy for the flow of materials between sectors. Such a level of detail is not available for physical measures of material flows between sectors that limit process model analyses to a small number of well-defined product or processes. Rather, the approach used in this analysis provides a comprehensive look at environmental impact and materials flows throughout the economy.¹³

Because the analysis quantifies “outliers” as a basis for identifying relatively high ranking materials, products, and services, the quality of the allocation of environmental impacts, resource use, and waste values across the baseline commodities is critical to the quality of the results. The mix of inputs and technologies underlying the allocations represent the mix of inputs and technologies as they existed as of 1998, based on available data upon which the statistics for

¹³ For more detailed discussions of the benefits and limitations of input-output LCA, in general, see, for example, Hendrickson, Lave and Matthews. *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach*. (Washington: Resources for the Future Press, 2006).

allocations were developed. In addition, the relative output of materials, products, and services may be different than what is reflected in the statistics used to allocate resource and material use. To the extent that the mix of inputs and the relative output of materials, products, and services have changed, the analysis may under- or over-represent the relative impacts, resource use, and waste associated with different materials, products, and services. As noted under the “Sensitivity Analyses,” some industries have experienced marked growth and decline between 1998 and 2008. Further, some industries, for example electronics, have made efficiency improvements.

The system used for classifying commodities will influence the results of the analysis. All things equal, more highly aggregated commodity categories will have a stronger influence on the results than more finely disaggregated categories. The BEA commodity classification system used as the baseline for this analysis is a mix of highly aggregate and less aggregated commodity categories and was developed for economic tracking and analysis.¹⁴ Grouping of materials, products, and services post-analysis could help assess the implications of this issue.

The analysis of different criteria depends critically on the quality of the underlying data. To the extent that underlying data (e.g., water use statistics associated with allocations) are of good quality, this will be reflected in the analysis. To the extent possible, the 2020 Vision Relative Ranking Analysis relied on the best available information, but it is recognized that some criteria may be better characterized than others and, within criteria, the data for some materials, products, and services may be better than the data for others. Industrial and commercial water use allocations used in this analysis rely on the least current data, though it was determined that when used in conjunction with a vector analysis methodology, this had little effect on the relative rankings.

Cross-walking across commodity classification systems introduces another source of uncertainty in the analysis. This issue is most relevant to the cross-walk between WRI and BEA classification systems, and impacts the degree of confidence in the material use and material waste criteria. While the cross-walk developed for the 2020 Vision Relative Ranking Analysis relied on a detailed review of various sources of information, the crosswalk could be improved by applying sector-specific expertise. It is hoped that this first attempt at such a crosswalk will catalyze such efforts and future analyses of materials management priorities will benefit as a result.

The 2020 Vision Relative Ranking Analysis was focused on better understanding the implications of U.S. consumption. As such, exports were left out of analysis and imports were included although assessed as if extracted, processed and manufactured in the U.S. While U.S. economy is relatively self-sufficient, export for final consumption is still significant, particularly for certain sectors (e.g., commercial aircraft industry). Studies of this issue suggest that excluding imports adds a small degree of uncertainty, mainly at the individual sector level.

¹⁴ For further discussion of the limitations associated with the use of BEA I-O data for economy-wide LCA, see, for example, Economic Input-Output Models for Environmental Life Cycle Assessment. Chris Hendrickson et al 1998. *Environmental Science and Technology*, April 1, 1998, (32)7, 184-191.

Finally, the CEDA 3.0 “characterization factors” module produces environmental impact scores according to the LCA methodologies developed by the Centre for Environmental Science, Leiden University (CML).¹⁵ These methodologies may represent a perspective that reflects to an extent the European environmental experience. The degree to which this would deviate from U.S.-derived methodologies and the effect on the relative ranking of materials, products, and services is unclear.

¹⁵ Suh, Sangwon (2004). *CEDA 3.0 User's Guide*. CML, Leiden University, Leiden, The Netherlands.

Appendix A
Summary of Top-Ranked Materials, Products, and Services
Based on Individual Criterion Analysis

Table A-1
Summary of Individual Criterion Analysis
Abiotic Depletion Potential (ADP)

Abiotic Depletion (ADP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Crude petroleum and natural gas	18.72	Crude petroleum and natural gas	16.72	Petroleum refining	15.52
2	Coal	11.21	Petroleum refining	7.81	Electric services (utilities)	11.87
3	Petroleum refining	0.96	Coal	7.75	Natural gas distribution	7.51
4	Industrial inorganic and organic chemicals	-0.05	Electric services (utilities)	6.16	Retail trade, except eating and drinking	3.22
5	Explosives	-0.06	Natural gas distribution	5.10	Motor vehicles and passenger car bodies	2.54
6	Dimension, crushed and broken stone	-0.06	Industrial inorganic and organic chemicals	1.41	Eating and drinking places	1.91
7	Copper ore	-0.06	Blast furnaces and steel mills	1.31	Hospitals	1.89
8	Iron and ferroalloy ores, and miscellaneous metal ores, n.e.c.	-0.06	Retail trade, except eating and drinking	0.81	Wholesale trade	1.10
9	Nonferrous metal ores, except copper	-0.06	Motor vehicles and passenger car bodies	0.80	Owner-occupied dwellings	0.99
10	<i>*only 9 materials/products/services have ADP direct emissions >0.</i>		Wholesale trade	0.76	New residential 1 unit structures, nonfarm	0.97
11			Real estate agents, managers, operators, and lessors	0.59	Real estate agents, managers, operators, and lessors	0.95
12			New residential 1 unit structures, nonfarm	0.47	Air transportation	0.92
13			Eating and drinking places	0.44	Other new construction	0.89
14			Air transportation	0.41	Apparel made from purchased materials	0.63
15			Trucking and courier services, except air	0.40	New office, industrial and commercial buildings construction	0.62
16			Miscellaneous plastics products, n.e.c.	0.36	Automotive repair shops and services	0.50
17			Motor vehicle parts and accessories	0.36	New highways, bridges, and other horizontal construction	0.41
18			Hospitals	0.35	Doctors and dentists	0.41
19			New office, industrial and commercial buildings construction	0.25	Computer and data processing services; including own-account software	0.39
20			Plastics materials and resins	0.24	Banking	0.38

Table A-2
Summary of Individual Criterion Analysis
Land Use/Land Competition (LUC)

Land Use/Land Competition Subfactor (LUC)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Meat animals	16.34	Meat animals	14.11	Meat packing plants	15.05
2	Dairy farm products	7.90	Meat packing plants	10.72	Eating and drinking places	11.31
3	Food grains	7.10	Dairy farm products	5.68	Poultry slaughtering and processing	6.85
4	Poultry and eggs	7.08	Eating and drinking places	5.04	Fluid milk	4.97
5	Feed grains	5.95	Poultry and eggs	4.51	Sausages and other prepared meat products	3.80
6	Miscellaneous livestock	1.71	Poultry slaughtering and processing	4.23	Natural, processed, and imitation cheese	3.15
7	Cotton	1.16	Food grains	4.10	Cereal breakfast foods	1.57
8	Miscellaneous crops	1.08	Feed grains	3.45	Poultry and eggs	1.35
9	Sugar crops	0.91	Fluid milk	2.77	Prepared flour mixes and doughs	1.34
10	General government industry	0.75	Natural, processed, and imitation cheese	2.51	Apparel made from purchased materials	1.21
11	Trucking and courier services, except air	0.69	Sausages and other prepared meat products	2.19	Food preparations, n.e.c.	1.21
12	Agricultural, forestry, and fishery services	0.56	Miscellaneous livestock	1.43	Hospitals	1.10
13	Other amusement and recreation services	0.32	Flour and other grain mill products	1.32	General government industry	1.09
14	Fruits	0.24	Leather tanning and finishing	0.85	Miscellaneous livestock	1.08
15	Vegetables	0.20	Prepared feeds, n.e.c.	0.61	Shoes, except rubber	1.01
16	Oil bearing crops	0.11	Sugar	0.59	Dog and cat food	1.00
17	Meat packing plants	0.04	Cotton	0.58	Bread, cake, and related products	0.90
18	Fluid milk	0.03	Prepared flour mixes and doughs	0.55	Other amusement and recreation services	0.89
19	Local and suburban transit and interurban highway passenger transportation	-0.01	Broadwoven fabric mills and fabric finishing plants	0.55	Frozen specialties, n.e.c.	0.78
20	Forestry products	-0.03	Agricultural, forestry, and fishery services	0.54	Dry, condensed, and evaporated dairy products	0.69

Table A-3
Summary of Individual Criterion Analysis
Global Warming Potential (GWP)

Global Warming Potential (GWP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	21.03	Electric services (utilities)	18.57	Electric services (utilities)	18.47
2	Crude petroleum and natural gas	2.78	Crude petroleum and natural gas	4.12	Retail trade, except eating and drinking	4.77
3	Blast furnaces and steel mills	2.72	Blast furnaces and steel mills	3.96	Motor vehicles and passenger car bodies	4.70
4	Sanitary services, steam supply, and irrigation systems	2.49	Petroleum refining	3.36	Eating and drinking places	4.35
5	Air transportation	1.53	Motor vehicles and passenger car bodies	3.06	Petroleum refining	3.51
6	Petroleum refining	1.45	Retail trade, except eating and drinking	2.45	Hospitals	2.98
7	Trucking and courier services, except air	1.41	Real estate agents, managers, operators, and lessors	2.34	Other new construction	2.27
8	Feed grains	0.95	New residential 1 unit structures, nonfarm	2.32	New residential 1 unit structures, nonfarm	2.25
9	Meat animals	0.95	Wholesale trade	2.26	Owner-occupied dwellings	2.06
10	Coal	0.65	Eating and drinking places	2.25	Real estate agents, managers, operators, and lessors	1.82
11	New residential 1 unit structures, nonfarm	0.63	Trucking and courier services, except air	2.18	Air transportation	1.73
12	Industrial inorganic and organic chemicals	0.54	Sanitary services, steam supply, and irrigation systems	2.15	Meat packing plants	1.69
13	Paper and paperboard mills	0.48	Meat animals	1.73	Wholesale trade	1.62
14	Fruits	0.38	Air transportation	1.68	New office, industrial and commercial buildings construction	1.56
15	New office, industrial and commercial buildings construction	0.36	Industrial inorganic and organic chemicals	1.67	Apparel made from purchased materials	1.27
16	Vegetables	0.31	Motor vehicle parts and accessories	1.50	Natural gas distribution	0.99
17	Cement, hydraulic	0.30	New office, industrial and commercial buildings construction	1.47	Banking	0.83
18	Water transportation	0.30	Meat packing plants	1.37	Trucking and courier services, except air	0.80
19	Poultry and eggs	0.28	Natural gas distribution	1.30	Automotive repair shops and services	0.80
20	Wholesale trade	0.28	Hospitals	1.23	New highways, bridges, and other horizontal construction	0.73

Table A-4
Summary of Individual Criterion Analysis
Ozone Layer Depletion Potential (ODP)

Ozone Layer Depletion Potential (ODP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Industrial inorganic and organic chemicals	19.46	Industrial inorganic and organic chemicals	17.04	Motor vehicles and passenger car bodies	12.22
2	Primary aluminum	5.27	Miscellaneous plastics products, n.e.c.	5.05	Hospitals	7.21
3	Miscellaneous repair shops	4.29	Plastics materials and resins	4.50	New residential 1 unit structures, nonfarm	5.97
4	Plastics materials and resins	3.19	Motor vehicles and passenger car bodies	4.50	Retail trade, except eating and drinking	5.38
5	Synthetic rubber	3.02	Primary aluminum	4.42	Owner-occupied dwellings	5.06
6	Mineral wool	2.70	New residential 1 unit structures, nonfarm	3.43	Industrial inorganic and organic chemicals	4.95
7	Primary nonferrous metals, n.e.c.	2.51	Miscellaneous repair shops	2.72	Other new construction	4.37
8	Surface active agents	2.04	Motor vehicle parts and accessories	2.54	Eating and drinking places	4.15
9	Cut stone and stone products	1.22	Wholesale trade	2.20	New office, industrial and commercial buildings construction	3.24
10	Miscellaneous plastics products, n.e.c.	1.16	Synthetic rubber	2.10	Apparel made from purchased materials	3.12
11	Lead pencils and art goods	1.00	Primary nonferrous metals, n.e.c.	1.87	Wholesale trade	2.89
12	Primary metal products, n.e.c.	0.81	Real estate agents, managers, operators, and lessors	1.84	Petroleum refining	2.85
13	Other repair and maintenance construction	0.74	Hospitals	1.69	Real estate agents, managers, operators, and lessors	2.63
14	Manufacturing industries, n.e.c.	0.70	New office, industrial and commercial buildings construction	1.66	New additions & alterations, nonfarm, construction	2.40
15	Petroleum refining	0.68	Aluminum rolling and drawing	1.65	Drugs	2.35
16	Pesticides and agricultural chemicals, n.e.c.	0.58	Mineral wool	1.62	Doctors and dentists	1.76
17	Nitrogenous and phosphatic fertilizers	0.54	Blast furnaces and steel mills	1.55	Automotive repair shops and services	1.74
18	Products of petroleum and coal, n.e.c.	0.54	Petroleum refining	1.44	Computer and data processing services; including own-account software	1.70
19	Photographic equipment and supplies	0.52	Retail trade, except eating and drinking	1.44	Soap and other detergents	1.68
20	Pipe, valves, and pipe fittings	0.50	Other repair and maintenance construction	1.33	Electric services (utilities)	1.65

Table A-5
Summary of Individual Criterion Analysis
Human Toxicity Potential (HTP)

Human Toxicity Potential (HTP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	13.70	Electric services (utilities)	9.62	Electric services (utilities)	11.87
2	Paper and paperboard mills	7.53	Paper and paperboard mills	7.41	Motor vehicles and passenger car bodies	9.96
3	Industrial inorganic and organic chemicals	6.57	Industrial inorganic and organic chemicals	7.03	Retail trade, except eating and drinking	6.18
4	Pulp mills	5.64	Primary smelting and refining of copper	6.17	Eating and drinking places	4.83
5	Photographic equipment and supplies	5.40	Motor vehicles and passenger car bodies	5.27	Hospitals	4.82
6	Copper ore	4.87	Photographic equipment and supplies	3.35	Apparel made from purchased materials	3.83
7	Nonmetallic mineral products, n.e.c.	4.54	Pulp mills	3.34	Photographic equipment and supplies	3.78
8	Primary aluminum	4.01	Wholesale trade	3.27	New residential 1 unit structures, nonfarm	3.61
9	Primary smelting and refining of copper	3.40	Copper ore	3.26	Other new construction	3.49
10	Nonferrous metal ores, except copper	3.38	Motor vehicle parts and accessories	3.18	Owner-occupied dwellings	3.38
11	Plastics materials and resins	2.66	Primary nonferrous metals, n.e.c.	3.13	Wholesale trade	2.95
12	Gum and wood chemicals	2.50	Primary aluminum	3.11	New highways, bridges, and other horizontal construction	2.74
13	Primary nonferrous metals, n.e.c.	1.97	Miscellaneous plastics products, n.e.c.	3.02	New office, industrial and commercial buildings construction	2.64
14	New highways, bridges, and other horizontal construction	1.41	New residential 1 unit structures, nonfarm	2.95	Real estate agents, managers, operators, and lessors	2.12
15	Synthetic rubber	1.28	Plastics materials and resins	2.69	Computer and data processing services; including own-account software	1.83
16	Wood containers, n.e.c.	1.19	Blast furnaces and steel mills	2.62	Automotive repair shops and services	1.46
17	Brick and structural clay tile	1.18	Nonmetallic mineral products, n.e.c.	2.49	Petroleum refining	1.43
18	Sanitary services, steam supply, and irrigation systems	1.09	Retail trade, except eating and drinking	2.46	Doctors and dentists	1.41
19	Nitrogenous and phosphatic fertilizers	0.87	Nonferrous metal ores, except copper	2.17	Banking	1.35
20	Coal	0.84	Real estate agents, managers, operators, and lessors	2.14	Gum and wood chemicals	1.25

Table A-6
Summary of Individual Criterion Analysis
Freshwater Aquatic Ecotoxicity Potential (FAETP)

Freshwater Aquatic Ecotoxicity Potential (FAETP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Cotton	19.46	Cotton	14.46	Apparel made from purchased materials	17.76
2	Feed grains	7.25	Broadwoven fabric mills and fabric finishing plants	9.80	Eating and drinking places	7.19
3	Tree nuts	3.56	Apparel made from purchased materials	6.59	Meat packing plants	3.71
4	Miscellaneous crops	3.30	Feed grains	5.42	Fruits	3.54
5	Fruits	3.11	Yarn mills and finishing of textiles, n.e.c.	4.89	Vegetables	3.17
6	Vegetables	2.26	Meat animals	2.87	Food preparations, n.e.c.	2.78
7	Sugar crops	1.91	Eating and drinking places	2.64	Housefurnishings, n.e.c.	2.73
8	Sanitary services, steam supply, and irrigation systems	0.80	Tree nuts	2.44	Motor vehicles and passenger car bodies	2.72
9	Agricultural, forestry, and fishery services	0.58	Miscellaneous crops	2.29	Salted and roasted nuts and seeds	2.43
10	Copper ore	0.31	Fruits	2.22	Carpets and rugs	2.05
11	Tobacco	0.29	Meat packing plants	2.16	Tree nuts	2.00
12	Paper and paperboard mills	0.28	Sugar	1.83	Candy and other confectionery products	1.94
13	Industrial inorganic and organic chemicals	0.22	Dairy farm products	1.67	Fluid milk	1.83
14	Pulp mills	0.19	Vegetables	1.60	Hospitals	1.66
15	Photographic equipment and supplies	0.18	Knit fabric mills	1.50	Sugar	1.31
16	Food grains	0.10	Sugar crops	1.27	Natural, processed, and imitation cheese	1.13
17	Other amusement and recreation services	0.10	Motor vehicles and passenger car bodies	1.16	Broadwoven fabric mills and fabric finishing plants	1.03
18	Nonferrous metal ores, except copper	0.08	Carpets and rugs	1.11	Retail trade, except eating and drinking	0.99
19	Primary smelting and refining of copper	0.05	Salted and roasted nuts and seeds	1.06	Cigarettes	0.88
20	Plastics materials and resins	0.05	Food preparations, n.e.c.	1.00	Sausages and other prepared meat products	0.85

Table A-7
Summary of Individual Criterion Analysis
Marine Aquatic Ecotoxicity Potential (MAETP)

Marine Aquatic Ecotoxicity Potential (MAETP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	21.38	Electric services (utilities)	20.46	Electric services (utilities)	20.63
2	Primary aluminum	3.30	Primary aluminum	3.77	Retail trade, except eating and drinking	3.62
3	Brick and structural clay tile	2.63	Brick and structural clay tile	2.30	Motor vehicles and passenger car bodies	3.43
4	Sanitary services, steam supply, and irrigation systems	0.74	Motor vehicles and passenger car bodies	2.20	Eating and drinking places	2.00
5	Coal	0.62	New residential 1 unit structures, nonfarm	1.87	Hospitals	1.93
6	Paper and paperboard mills	0.49	Retail trade, except eating and drinking	1.84	New residential 1 unit structures, nonfarm	1.85
7	Industrial inorganic and organic chemicals	0.47	Motor vehicle parts and accessories	1.71	Owner-occupied dwellings	1.62
8	Photographic equipment and supplies	0.32	Real estate agents, mgrs, operators, and lessors	1.64	Real estate agents, managers, operators, and lessors	1.30
9	Primary metal products, n.e.c.	0.29	Aluminum rolling and drawing	1.45	Other new construction	1.28
10	Pulp mills	0.24	Wholesale trade	1.37	New office, industrial and commercial buildings construction	1.04
11	Plastics materials and resins	0.23	Industrial inorganic and organic chemicals	1.17	Wholesale trade	1.00
12	Glass and glass products, except containers	0.22	Blast furnaces and steel mills	1.07	Apparel made from purchased materials	0.84
13	Manmade organic fibers, except cellulosic	0.13	Eating and drinking places	0.98	Automotive repair shops and services	0.61
14	Copper ore	0.12	New office, industrial and commercial buildings construction	0.96	New additions & alterations, nonfarm, construction	0.53
15	Ceramic wall and floor tile	0.12	Paper and paperboard mills	0.89	Computer and data processing services; including own-account software	0.51
16	Cellulosic manmade fibers	0.10	Hospitals	0.78	Petroleum refining	0.51
17	Primary nonferrous metals, n.e.c.	0.07	Miscellaneous plastics products, n.e.c.	0.74	Banking	0.44
18	Blast furnaces and steel mills	0.06	Sanitary services, steam supply, and irrigation systems	0.68	Doctors and dentists	0.43
19	Gum and wood chemicals	0.06	Owner-occupied dwellings	0.63	Nursing and personal care facilities	0.38
20	Chemicals and chemical preparations, n.e.c.	0.02	Coal	0.61	Telephone, telegraph communications, and communications services n.e.c.	0.37

Table A-8
Summary of Individual Criterion Analysis
Terrestrial Ecotoxicity Potential (TETP)

Terrestrial Ecotoxicity Potential (TETP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Cotton	19.57	Cotton	14.39	Apparel made from purchased materials	17.71
2	Feed grains	7.02	Broadwoven fabric mills and fabric finishing plants	9.81	Eating and drinking places	7.16
3	Tree nuts	3.31	Apparel made from purchased materials	6.68	Meat packing plants	3.52
4	Miscellaneous crops	2.96	Feed grains	5.21	Motor vehicles and passenger car bodies	3.48
5	Fruits	2.73	Yarn mills and finishing of textiles, n.e.c.	4.88	Vegetables	3.43
6	Vegetables	2.52	Meat animals	2.75	Fruits	3.11
7	Sugar crops	1.77	Eating and drinking places	2.66	Housefurnishings, n.e.c.	2.68
8	Sanitary services, steam supply, and irrigation systems	1.11	Tree nuts	2.21	Food preparations, n.e.c.	2.47
9	Copper ore	0.93	Meat packing plants	2.07	Salted and roasted nuts and seeds	2.18
10	Paper and paperboard mills	0.91	Miscellaneous crops	1.99	Carpets and rugs	2.02
11	Pulp mills	0.69	Fruits	1.96	Hospitals	2.01
12	Industrial inorganic and organic chemicals	0.69	Vegetables	1.77	Tree nuts	1.79
13	Photographic equipment and supplies	0.63	Sugar	1.65	Candy and other confectionery products	1.76
14	Agricultural, forestry, and fishery services	0.56	Dairy farm products	1.58	Fluid milk	1.73
15	Nonferrous metal ores, except copper	0.32	Motor vehicles and passenger car bodies	1.54	Retail trade, except eating and drinking	1.47
16	Primary smelting and refining of copper	0.29	Knit fabric mills	1.49	Sugar	1.16
17	Gum and wood chemicals	0.25	Paper and paperboard mills	1.14	Natural, processed, and imitation cheese	1.06
18	Tobacco	0.24	Sugar crops	1.14	Broadwoven fabric mills and fabric finishing plants	0.99
19	Plastics materials and resins	0.23	Carpets and rugs	1.10	Owner-occupied dwellings	0.92
20	Primary aluminum	0.19	Industrial inorganic and organic chemicals	1.08	New residential 1 unit structures, nonfarm	0.84

Table A-9
Summary of Individual Criterion Analysis
Freshwater Sedimental Ecotoxicity Potential (FSETP)

Freshwater Sedimental Ecotoxicity Potential (FSETP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	21.30	Electric services (utilities)	20.14	Electric services (utilities)	20.34
2	Primary aluminum	3.39	Primary aluminum	3.82	Retail trade, except eating and drinking	3.87
3	Brick and structural clay tile	2.60	Motor vehicles and passenger car bodies	2.47	Motor vehicles and passenger car bodies	3.87
4	Sanitary services, steam supply, and irrigation systs.	0.99	Brick and structural clay tile	2.22	Eating and drinking places	2.20
5	Paper and paperboard mills	0.92	New residential 1 unit structures, nonfarm	2.00	Hospitals	2.16
6	Industrial inorganic and organic chemicals	0.81	Retail trade, except eating and drinking	1.95	New residential 1 unit structures, nonfarm	1.98
7	Coal	0.66	Motor vehicle parts and accessories	1.85	Owner-occupied dwellings	1.75
8	Photographic equipment and supplies	0.64	Real estate agents, managers, operators, and lessors	1.74	Other new construction	1.43
9	Pulp mills	0.58	Industrial inorganic and organic chemicals	1.67	Real estate agents, managers, operators, and lessors	1.39
10	Copper ore	0.44	Wholesale trade	1.57	New office, industrial and commercial buildings construction	1.15
11	Plastics materials and resins	0.39	Paper and paperboard mills	1.51	Wholesale trade	1.15
12	Primary metal products, n.e.c.	0.31	Aluminum rolling and drawing	1.47	Apparel made from purchased materials	1.08
13	Glass and glass products, except containers	0.23	Blast furnaces and steel mills	1.19	Automotive repair shops and services	0.68
14	Gum and wood chemicals	0.21	Eating and drinking places	1.07	Computer and data processing services; including own-account software	0.61
15	Manmade organic fibers, except cellulosic	0.19	New office, industrial and commercial buildings construction	1.05	Petroleum refining	0.57
16	Primary nonferrous metals, n.e.c.	0.15	Miscellaneous plastics products, n.e.c.	0.96	New additions & alterations, nonfarm, construction	0.57
17	Cellulosic manmade fibers	0.13	Sanitary services, steam supply, and irrigation systems	0.89	Photographic equipment and supplies	0.55
18	Primary smelting and refining of copper	0.11	Hospitals	0.87	Banking	0.52
19	Ceramic wall and floor tile	0.11	Owner-occupied dwellings	0.67	Doctors and dentists	0.51
20	Nonferrous metal ores, except copper	0.09	Plastics materials and resins	0.66	Telephone, telegraph communications, and communications services n.e.c.	0.43

Table A-10
Summary of Individual Criterion Analysis
Marine Sedimental Ecotoxicity Potential (MSETP)

Marine Sedimental Ecotoxicity Potential (MSETP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Paper and paperboard mills	12.20	Paper and paperboard mills	12.55	Motor vehicles and passenger car bodies	9.01
2	Pulp mills	9.56	Industrial inorganic and organic chemicals	8.86	Photographic equipment and supplies	8.43
3	Industrial inorganic and organic chemicals	9.32	Pulp mills	6.23	Retail trade, except eating and drinking	6.90
4	Photographic equipment and supplies	8.88	Photographic equipment and supplies	5.96	Apparel made from purchased materials	6.13
5	Gum and wood chemicals	4.38	Miscellaneous plastics products, n.e.c.	3.72	Hospitals	6.13
6	Plastics materials and resins	3.42	Motor vehicles and passenger car bodies	3.67	Eating and drinking places	5.81
7	Primary aluminum	2.80	Wholesale trade	3.66	Wholesale trade	4.22
8	Wood containers, n.e.c.	2.39	Plastics materials and resins	3.56	New residential 1 unit structures, nonfarm	3.51
9	Synthetic rubber	1.98	Paperboard containers and boxes	3.55	Owner-occupied dwellings	3.43
10	Nitrogenous and phosphatic fertilizers	1.49	Gum and wood chemicals	3.09	Gum and wood chemicals	3.25
11	Wood products, n.e.c.	1.34	Advertising	2.66	Other new construction	3.08
12	Primary nonferrous metals, n.e.c.	1.29	Primary aluminum	2.28	Sanitary paper products	2.81
13	Apparel made from purchased materials	1.23	New residential 1 unit structures, nonfarm	2.22	Computer and data processing services; including own-account software	2.61
14	Surface active agents	1.12	Retail trade, except eating and drinking	2.15	New office, industrial and commercial buildings construction	2.37
15	Distilled and blended liquors	0.78	Apparel made from purchased materials	1.85	Industrial inorganic and organic chemicals	2.13
16	Laboratory and optical instruments	0.76	Eating and drinking places	1.79	Doctors and dentists	1.99
17	Nonwoven fabrics	0.65	Motor vehicle parts and accessories	1.73	Real estate agents, managers, operators, and lessors	1.97
18	Cut stone and stone products	0.58	Hospitals	1.58	Banking	1.89
19	Primary metal products, n.e.c.	0.58	Real estate agents, managers, operators, and lessors	1.54	Insurance carriers	1.79
20	Cotton	0.54	Commercial printing	1.38	Drugs	1.72

Table A-11
Summary of Individual Criterion Analysis
Photochemical Oxidation Potential (POCP)

Photochemical Oxidation Potential (POCP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	19.89	Electric services (utilities)	16.04	Electric services (utilities)	15.76
2	Trucking and courier services, except air	5.19	Trucking and courier services, except air	5.60	Motor vehicles and passenger car bodies	6.63
3	Sanitary services, steam supply, and irrigation systems	3.75	Motor vehicles and passenger car bodies	4.39	Retail trade, except eating and drinking	5.90
4	Blast furnaces and steel mills	2.65	Crude petroleum and natural gas	4.27	Eating and drinking places	5.00
5	Crude petroleum and natural gas	2.58	Blast furnaces and steel mills	3.74	Other amusement and recreation services	3.71
6	Other amusement and recreation services	2.03	New residential 1 unit structures, nonfarm	3.30	Hospitals	3.55
7	Miscellaneous repair shops	1.51	Petroleum refining	3.27	Petroleum refining	3.39
8	Industrial inorganic and organic chemicals	1.37	Wholesale trade	3.24	New residential 1 unit structures, nonfarm	3.16
9	Petroleum refining	1.28	Retail trade, except eating and drinking	3.06	Owner-occupied dwellings	2.95
10	Paper and paperboard mills	1.16	Sanitary services, steam supply, and irrigation systems	2.95	Other new construction	2.93
11	New residential 1 unit structures, nonfarm	1.12	Real estate agents, managers, operators, and lessors	2.93	Wholesale trade	2.29
12	New highways, bridges, and other horizontal construction	0.95	Eating and drinking places	2.60	Real estate agents, managers, operators, and lessors	2.25
13	Motor vehicles and passenger car bodies	0.84	Industrial inorganic and organic chemicals	2.54	Trucking and courier services, except air	2.17
14	Primary aluminum	0.73	Motor vehicle parts and accessories	1.96	New highways, bridges, and other horizontal construction	2.12
15	Feed grains	0.73	New office, industrial and commercial buildings construction	1.95	New office, industrial and commercial buildings construction	2.04
16	Wholesale trade	0.72	Miscellaneous plastics products, n.e.c.	1.85	Meat packing plants	1.43
17	Meat animals	0.68	Other amusement and recreation services	1.56	Apparel made from purchased materials	1.41
18	Air transportation	0.67	Natural gas distribution	1.56	Banking	1.29
19	Carbon black	0.66	Paper and paperboard mills	1.50	Natural gas distribution	1.16
20	Miscellaneous plastics products, n.e.c.	0.65	Hospitals	1.48	Automotive repair shops and services	1.07

Table A-12
Summary of Individual Criterion Analysis
Acidification Potential (AP)

Acidification Potential (AP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	21.74	Electric services (utilities)	20.87	Electric services (utilities)	20.75
2	Blast furnaces and steel mills	0.88	Crude petroleum and natural gas	2.10	Retail trade, except eating and drinking	3.64
3	Petroleum refining	0.83	Petroleum refining	2.02	Motor vehicles and passenger car bodies	2.65
4	Crude petroleum and natural gas	0.79	Retail trade, except eating and drinking	1.89	Eating and drinking places	2.17
5	Paper and paperboard mills	0.72	Blast furnaces and steel mills	1.84	Petroleum refining	2.11
6	Cement, hydraulic	0.60	Motor vehicles and passenger car bodies	1.72	Hospitals	1.96
7	Industrial inorganic and organic chemicals	0.59	Wholesale trade	1.48	New residential 1 unit structures, nonfarm	1.09
8	Trucking and courier services, except air	0.59	Industrial inorganic and organic chemicals	1.46	Other new construction	1.08
9	Railroads and related services	0.49	Real estate agents, managers, operators, and lessors	1.38	Real estate agents, managers, operators, and lessors	1.07
10	Natural gas transportation	0.46	New residential 1 unit structures, nonfarm	1.12	Owner-occupied dwellings	1.07
11	Sanitary services, steam supply, and irrigation systems	0.25	Eating and drinking places	1.10	Wholesale trade	1.06
12	Primary aluminum	0.25	Paper and paperboard mills	1.10	New office, industrial and commercial buildings construction	0.76
13	Water transportation	0.21	Trucking and courier services, except air	1.07	Apparel made from purchased materials	0.64
14	Primary smelting and refining of copper	0.21	Motor vehicle parts and accessories	0.88	Natural gas distribution	0.61
15	Pulp mills	0.18	Hospitals	0.82	Banking	0.49
16	Motor vehicles and passenger car bodies	0.06	Natural gas distribution	0.80	Computer and data processing services; including own-account software	0.48
17	New residential 1 unit structures, nonfarm	0.06	Miscellaneous plastics products, n.e.c.	0.76	Automotive repair shops and services	0.48
18	Sugar	0.05	New office, industrial and commercial buildings construction	0.70	Doctors and dentists	0.44
19	Plastics materials and resins	0.05	Cement, hydraulic	0.56	Nursing and personal care facilities	0.39
20	Nitrogenous and phosphatic fertilizers	0.05	Other new construction	0.50	Trucking and courier services, except air	0.38

Table A-13
Summary of Individual Criterion Analysis
Eutrophication Potential (EP)

Eutrophication Potential (EP)						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	14.94	Electric services (utilities)	12.29	Electric services (utilities)	13.53
2	Cotton	8.32	Cotton	6.29	Eating and drinking places	8.73
3	Miscellaneous crops	7.56	Miscellaneous crops	5.59	Apparel made from purchased materials	7.17
4	Food grains	7.25	Food grains	5.53	Food preparations, n.e.c.	4.87
5	Feed grains	6.07	Feed grains	4.90	Motor vehicles and passenger car bodies	4.73
6	Trucking and courier services, except air	2.67	Broadwoven fabric mills and fabric finishing plants	4.58	Retail trade, except eating and drinking	4.02
7	Railroads and related services	2.23	Eating and drinking places	4.16	Meat packing plants	3.28
8	Natural gas transportation	2.13	Crude petroleum and natural gas	3.62	Hospitals	3.18
9	Sugar crops	2.11	Apparel made from purchased materials	3.28	Petroleum refining	2.90
10	Fruits	1.63	Meat animals	3.11	New residential 1 unit structures, nonfarm	2.10
11	Crude petroleum and natural gas	1.35	Trucking and courier services, except air	2.90	Cereal breakfast foods	2.05
12	Water transportation	1.05	Motor vehicles and passenger car bodies	2.71	Owner-occupied dwellings	2.04
13	Industrial inorganic and organic chemicals	0.74	Petroleum refining	2.46	Other new construction	1.87
14	Cement, hydraulic	0.73	Meat packing plants	2.44	Prepared flour mixes and doughs	1.74
15	Petroleum refining	0.71	Food preparations, n.e.c.	2.37	Real estate agents, managers, operators, and lessors	1.58
16	Blast furnaces and steel mills	0.69	Yarn mills and finishing of textiles, n.e.c.	2.12	Fruits	1.50
17	Paper and paperboard mills	0.67	Industrial inorganic and organic chemicals	2.11	Bread, cake, and related products	1.48
18	Sanitary services, steam supply, and irrigation systems	0.67	Sugar	2.02	Fluid milk	1.47
19	Agricultural, forestry, and fishery services	0.46	New residential 1 unit structures, nonfarm	1.91	Wholesale trade	1.47
20	New residential 1 unit structures, nonfarm	0.39	Wholesale trade	1.83	Natural gas distribution	1.35

Table A-14
Summary of Individual Criterion Analysis
Material Use (MU)

Material Use						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	New residential 1 unit structures, nonfarm	11.40	New residential 1 unit structures, nonfarm	12.80	New highways, bridges, and other horizontal construction	11.80
2	Dimension, crushed and broken stone	9.97	New highways, bridges, and other horizontal construction	6.69	New residential 1 unit structures, nonfarm	10.90
3	Sand and gravel	8.71	Dimension, crushed and broken stone	6.58	Owner-occupied dwellings	7.56
4	New highways, bridges, and other horizontal construction	6.45	Sand and gravel	5.71	Other new construction	7.14
5	Coal	5.56	Real estate agents, managers, operators, and lessors	5.19	New office, industrial and commercial buildings construction	4.28
6	New office, industrial and commercial buildings construction	5.41	New office, industrial and commercial buildings construction	4.65	New additions & alterations, nonfarm, construction	4.20
7	Other new construction	4.74	Other new construction	4.30	Real estate agents, managers, operators, and lessors	3.60
8	Petroleum refining	4.11	Coal	4.07	Electric services (utilities)	3.41
9	Natural gas distribution	2.79	Owner-occupied dwellings	3.83	Petroleum refining	3.30
10	Feed grains	2.14	Electric services (utilities)	3.79	Retail trade, except eating and drinking	2.36
11	New additions & alterations, nonfarm, construction	1.91	Petroleum refining	3.55	Maintenance and repair of highways & streets	2.30
12	Iron and ferroalloy ores, and miscellaneous metal ores, n.e.c.	1.15	Ready-mixed concrete	2.94	Eating and drinking places	2.07
13	New residential garden and high-rise apartments construction	0.93	Natural gas distribution	2.60	Natural gas distribution	1.76
14	Cement, hydraulic	0.88	New additions & alterations, nonfarm, construction	2.19	Motor vehicles and passenger car bodies	1.68
15	Industrial inorganic and organic chemicals	0.81	Blast furnaces and steel mills	1.98	Hospitals	1.54
16	Forestry products	0.75	Feed grains	1.63	New residential garden and high-rise apartments construction	0.91
17	Sawmills and planing mills, general	0.51	Industrial inorganic and organic chemicals	1.47	Meat packing plants	0.89
18	Pulp mills	0.43	Maintenance and repair of highways & streets	1.34	Wholesale trade	0.66
19	Vegetables	0.40	Retail trade, except eating and drinking	1.28	Maintenance and repair of farm and nonfarm residential structures	0.65
20	Dairy farm products	0.24	Motor vehicles and passenger car bodies	1.15	Fluid milk	0.45

Table A-15
Summary of Individual Criterion Analysis
Material Waste (MW)

Material Waste						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Coal	14.30	Coal	11.76	Petroleum refining	14.70
2	Petroleum refining	13.59	Petroleum refining	11.45	Electric services (utilities)	11.60
3	Natural gas distribution	8.64	Electric services (utilities)	9.32	Natural gas distribution	7.62
4	Industrial inorganic and organic chemicals	2.05	Natural gas distribution	8.04	Retail trade, except eating and drinking	3.69
5	Forestry products	1.71	Industrial inorganic and organic chemicals	3.19	Motor vehicles and passenger car bodies	3.45
6	Sand and gravel	1.09	Blast furnaces and steel mills	2.87	Eating and drinking places	2.49
7	Pulp mills	0.80	Motor vehicles and passenger car bodies	1.75	Hospitals	2.34
8	Iron and ferroalloy ores, and miscellaneous metal ores, n.e.c.	0.73	New residential 1 unit structures, nonfarm	1.68	New residential 1 unit structures, nonfarm	2.08
9	Chemical and fertilizer minerals	0.56	Retail trade, except eating and drinking	1.46	Owner-occupied dwellings	1.91
10	Plastics materials and resins	0.45	Wholesale trade	1.46	Other new construction	1.47
11	Lime	0.35	Real estate agents, managers, operators, and lessors	1.41	Real estate agents, managers, operators, and lessors	1.40
12	Clay, ceramic, and refractory minerals	0.27	Forestry products	1.23	Wholesale trade	1.33
13	Meat animals	0.25	Paper and paperboard mills	1.19	New office, industrial and commercial buildings construction	1.08
14	Lubricating oils and greases	0.22	Miscellaneous plastics products, n.e.c.	0.99	Apparel made from purchased materials	1.03
15	Nitrogenous and phosphatic fertilizers	0.18	Eating and drinking places	0.95	Air transportation	0.88
16	Feed grains	0.16	Plastics materials and resins	0.86	New highways, bridges, and other horizontal construction	0.84
17	Minerals, ground or treated	0.12	Motor vehicle parts and accessories	0.85	Meat packing plants	0.70
18	Manmade organic fibers, except cellulosic	0.12	New office, industrial and commercial buildings construction	0.77	New additions & alterations, nonfarm, construction	0.64
19	Hardwood dimension and flooring mills	0.09	Hospitals	0.72	Automotive repair shops and services	0.62
20	Primary aluminum	0.06	Sand and gravel	0.69	Industrial inorganic and organic chemicals	0.54

Table A-16
Summary of Individual Criterion Analysis
Water Use (WU)

Water Use						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	8.66	Electric services (utilities)	8.61	Electric services (utilities)	8.52
2	Feed grains	0.35	Retail trade, except eating and drinking	1.54	Retail trade, except eating and drinking	2.92
3	Fruits	0.08	Wholesale trade	0.97	Eating and drinking places	1.68
4	Vegetables	0.06	Real estate agents, managers, operators, and lessors	0.94	Hospitals	1.40
5	Cotton	0.03	Eating and drinking places	0.88	Motor vehicles and passenger car bodies	1.25
6	Blast furnaces and steel mills	-0.00	Motor vehicles and passenger car bodies	0.81	Real estate agents, managers, operators, and lessors	0.72
7	Sanitary services, steam supply, and irrigation systems	-0.01	Hospitals	0.60	Wholesale trade	0.68
8	Industrial inorganic and organic chemicals	-0.01	Blast furnaces and steel mills	0.59	Apparel made from purchased materials	0.46
9	Paper and paperboard mills	-0.01	Industrial inorganic and organic chemicals	0.44	Owner-occupied dwellings	0.44
10	Petroleum refining	-0.02	New residential 1 unit structures, nonfarm	0.43	New residential 1 unit structures, nonfarm	0.41
11	Oil bearing crops	-0.02	Motor vehicle parts and accessories	0.42	Other new construction	0.40
12	Meat animals	-0.03	Miscellaneous plastics products, n.e.c.	0.36	Nursing and personal care facilities	0.36
13	Food grains	-0.03	Feed grains	0.35	Petroleum refining	0.34
14	Sugar crops	-0.03	Crude petroleum and natural gas	0.35	New office, industrial and commercial buildings construction	0.29
15	Crude petroleum and natural gas	-0.03	Petroleum refining	0.32	Computer and data processing services; including own-account software	0.28
16	Other amusement and recreation services	-0.03	New office, industrial and commercial buildings construction	0.27	Automotive repair shops and services	0.27
17	Agricultural, forestry, and fishery services	-0.04	Meat animals	0.27	Meat packing plants	0.26
18	Tree nuts	-0.04	Telephone, telegraph communications, and communications services n.e.c.	0.21	Banking	0.26
19	Real estate agents, managers, operators, and lessors	-0.04	Meat packing plants	0.21	Doctors and dentists	0.26
20	Greenhouse and nursery products	-0.04	Computer and data processing services; including own-account software	0.21	Other amusement and recreation services	0.26

Table A-17
Summary of Individual Criterion Analysis
Energy Use (EU)

Energy Use						
Rank	Direct Emissions		Intermediate Consumption		Final Consumption	
	Description	Vector Magnitude	Description	Vector Magnitude	Description	Vector Magnitude
1	Electric services (utilities)	21.49	Electric services (utilities)	20.14	Electric services (utilities)	19.87
2	Blast furnaces and steel mills	2.61	Blast furnaces and steel mills	3.78	Retail trade, except eating and drinking	5.16
3	Air transportation	1.50	Retail trade, except eating and drinking	2.72	Motor vehicles and passenger car bodies	3.50
4	Paper and paperboard mills	1.40	Wholesale trade	2.53	Eating and drinking places	2.70
5	Trucking and courier services, except air	1.14	Motor vehicles and passenger car bodies	2.30	Hospitals	2.36
6	Petroleum refining	0.78	Real estate agents, managers, operators, and lessors	1.82	Wholesale trade	1.80
7	Wholesale trade	0.77	Trucking and courier services, except air	1.73	Petroleum refining	1.78
8	Retail trade, except eating and drinking	0.63	Petroleum refining	1.70	Air transportation	1.69
9	Petroleum, natural gas, and solid mineral exploration	0.56	Air transportation	1.68	New residential 1 unit structures, nonfarm	1.47
10	Local and suburban transit and interurban highway passenger transportation	0.40	Paper and paperboard mills	1.66	Owner-occupied dwellings	1.41
11	Crude petroleum and natural gas	0.20	New residential 1 unit structures, nonfarm	1.53	Real estate agents, managers, operators, and lessors	1.40
12	Fruits	0.16	Crude petroleum and natural gas	1.51	Other new construction	1.30
13	Real estate agents, managers, operators, and lessors	0.14	Eating and drinking places	1.39	New office, industrial and commercial buildings construction	0.98
14	Railroads and related services	0.13	Motor vehicle parts and accessories	1.14	Apparel made from purchased materials	0.89
15	Sanitary services, steam supply, and irrigation systems	0.13	Hospitals	1.00	Automotive repair shops and services	0.79
16	Automotive repair shops and services	0.12	New office, industrial and commercial buildings construction	0.93	Local and suburban transit and interurban highway passenger transportation	0.71
17	New residential 1 unit structures, nonfarm	0.12	Industrial inorganic and organic chemicals	0.74	Computer and data processing services; including own-account software	0.69
18	Eating and drinking places	0.11	Miscellaneous plastics products, n.e.c.	0.71	Banking	0.64
19	Other business services	0.10	Natural gas distribution	0.69	Trucking and courier services, except air	0.63
20	Automotive rental and leasing, without drivers	0.07	Other new construction	0.62	Doctors and dentists	0.61

Appendix B

Summary of System Perspectives Analysis

Table B-1
Effect of Change in Perspective on Ranking Based on Global Warming Potential
Change from Direct Impact/Waste/Use Perspective

Direct Impact/Use/Waste		Intermediate Consumption		Final Consumption	
Rank	Material/Product/Service	Rank	Change	Rank	Change
1	Electric services (utilities)	1	0	1	0
2	Crude petroleum and natural gas	2	0	316	↓314
3	Blast furnaces and steel mills	3	0	370	↓367
4	Sanitary services, steam supply, and irrigation systems	12	↓8	25	↓21
5	Air transportation	14	↓9	11	↓6
6	Petroleum refining	4	↑2	5	↑1
7	Trucking and courier services, except air	11	↓4	18	↓11
8	Feed grains	23	↓15	239	↓231
9	Meat animals	13	↓4	435	↓426
10	Coal	27	↓17	326	↓316
11	New residential 1 unit structures, nonfarm	8	↑3	8	↑3
12	Industrial inorganic and organic chemicals	15	↓3	53	↓41
13	Paper and paperboard mills	25	↓12	182	↓169
14	Fruits	44	↓30	37	↓23
15	New office, industrial and commercial buildings construction	17	↓2	14	↑1
16	Vegetables	58	↓42	35	↓19
17	Cement, hydraulic	56	↓39	435	↓418
18	Water transportation	48	↓30	44	↓26
19	Poultry and eggs	38	↓19	90	↓71
20	Wholesale trade	9	↑11	13	↑7
21	Motor vehicles and passenger car bodies	5	↑16	3	↑18
22	Water supply and sewerage systems	40	↓18	26	↓4
23	Miscellaneous plastics products, n.e.c.	21	↑2	95	↓72
24	Other new construction	22	↑2	7	↑17
25	Lime	82	↓57	406	↓381
26	Railroads and related services	57	↓31	103	↓77
27	U.S. Postal Service	45	↓18	73	↓46
28	Oil bearing crops	72	↓44	396	↓368
29	Concrete products, except block and brick	70	↓41	369	↓340
30	Plastics materials and resins	33	↓3	411	↓381
31	Iron and steel foundries	65	↓34	391	↓360
32	Motor vehicle parts and accessories	16	↑16	87	↓55
33	Food grains	94	↓61	346	↓313
34	Retail trade, except eating and drinking	6	↑28	2	↑32
35	Eating and drinking places	10	↑25	4	↑31
36	Other State and local government enterprises	54	↓18	29	↑7
37	Real estate agents, managers, operators, and lessors	7	↑30	10	↑27
38	Hospitals	20	↑18	6	↑32
39	Ready-mixed concrete	55	↓16	435	↓396
40	Dairy farm products	37	↑3	353	↓313

Table B-2

Effect of Change in Perspective on Ranking Based on Global Warming Potential
Change from Intermediate Consumption Perspective

Direct Impact/Use/Waste		Intermediate Consumption		Final Consumption	
Rank	Change	Rank	Material/Product/Service	Rank	Change
1	0	1	Electric services (utilities)	1	0
2	0	2	Crude petroleum and natural gas	316	↓314
3	0	3	Blast furnaces and steel mills	370	↓367
6	↓2	4	Petroleum refining	5	↓1
21	↓16	5	Motor vehicles and passenger car bodies	3	↑2
34	↓28	6	Retail trade, except eating and drinking	2	↑4
37	↓30	7	Real estate agents, managers, operators, and lessors	10	↓3
11	↓3	8	New residential 1 unit structures, nonfarm	8	0
20	↓11	9	Wholesale trade	13	↓4
35	↓25	10	Eating and drinking places	4	↑6
7	↑4	11	Trucking and courier services, except air	18	↓7
4	↑8	12	Sanitary services, steam supply, and irrigation systems	25	↓13
9	↑4	13	Meat animals	435	↓422
5	↑9	14	Air transportation	11	↑3
12	↑3	15	Industrial inorganic and organic chemicals	53	↓38
32	↓16	16	Motor vehicle parts and accessories	87	↓71
15	↑2	17	New office, industrial and commercial buildings construction	14	↑3
75	↓57	18	Meat packing plants	12	↑6
189	↓170	19	Natural gas distribution	16	↑3
38	↓18	20	Hospitals	6	↑14
23	↓2	21	Miscellaneous plastics products, n.e.c.	95	↓74
24	↓2	22	Other new construction	7	↑15
8	↑15	23	Feed grains	239	↓216
472	↓448	24	Owner-occupied dwellings	9	↑15
13	↑12	25	Paper and paperboard mills	182	↓157
48	↓22	26	Other repair and maintenance construction	55	↓29
10	↑17	27	Coal	326	↓299
132	↓104	28	Telephone, telegraph communications, and communications services n.e.c.	28	0
61	↓32	29	Automotive repair shops and services	19	↑10
47	↓17	30	Banking	17	↑13
49	↓18	31	Apparel made from purchased materials	15	↑16
146	↓114	32	Computer and data processing services; including own-account software	22	↑10
30	↑3	33	Plastics materials and resins	411	↓378
159	↓125	34	Poultry slaughtering and processing	21	↑13
50	↓15	35	Advertising	274	↓239
100	↓64	36	Computer peripheral equipment	41	↓5
40	↓3	37	Dairy farm products	353	↓316
19	↑19	38	Poultry and eggs	90	↓52
70	↓31	39	Other electronic components	321	↓282
22	↑18	40	Water supply and sewerage systems	26	↑14

Table B-3

Effect of Change in Perspective on Ranking Based on Global Warming Potential
Change from Final Consumption Perspective

Direct Emissions Perspective		Intermediate Consumption		Final Consumption	
Rank	Change	Rank	Change	Rank	Material/Product/Service
1	0	1	0	1	Electric services (utilities)
34	↓32	6	↓4	2	Retail trade, except eating and drinking
21	↓18	5	↓2	3	Motor vehicles and passenger car bodies
35	↓31	10	↓6	4	Eating and drinking places
6	↓1	4	↑1	5	Petroleum refining
38	↓32	20	↓14	6	Hospitals
24	↓17	22	↓15	7	Other new construction
11	↓3	8	0	8	New residential 1 unit structures, nonfarm
472	↓463	24	↓15	9	Owner-occupied dwellings
37	↓27	7	↑3	10	Real estate agents, managers, operators, and lessors
5	↑6	14	↓3	11	Air transportation
75	↓63	18	↓6	12	Meat packing plants
20	↓7	9	↑4	13	Wholesale trade
15	↓1	17	↓3	14	New office, industrial and commercial buildings construction
49	↓34	31	↓16	15	Apparel made from purchased materials
189	↓173	19	↓3	16	Natural gas distribution
47	↓30	30	↓13	17	Banking
7	↑11	11	↑7	18	Trucking and courier services, except air
61	↓42	29	↓10	19	Automotive repair shops and services
43	↓23	50	↓30	20	New highways, bridges, and other horizontal construction
159	↓138	34	↓13	21	Poultry slaughtering and processing
146	↓124	32	↓10	22	Computer and data processing servs.; including own-account software
151	↓128	62	↓39	23	Doctors and dentists
55	↓31	60	↓36	24	New additions & alterations, nonfarm, construction
4	↑21	12	↑13	25	Sanitary services, steam supply, and irrigation systems
22	↑4	40	↓14	26	Water supply and sewerage systems
233	↓206	51	↓24	27	Insurance carriers
132	↓104	28	0	28	Telephone, telegraph communications, and communications services n.e.c.
36	↓7	54	↓25	29	Other State and local government enterprises
157	↓127	73	↓43	30	Nursing and personal care facilities
98	↓67	83	↓52	31	Other amusement and recreation services
156	↓124	86	↓54	32	Social services, n.e.c.
174	↓141	64	↓31	33	Fluid milk
142	↓108	63	↓29	34	Sausages and other prepared meat products
16	↑19	58	↓23	35	Vegetables
52	↓16	66	↓30	36	Drugs
14	↑23	44	↓7	37	Fruits
134	↓96	88	↓50	38	Bottled and canned soft drinks
187	↓148	61	↓22	39	Electronic computers
145	↓105	53	↓13	40	Automotive rental and leasing, without drivers

Appendix C

Summary of Criteria Layering Analysis

Table C-1

Effect of layering Criteria on Ranking, Starting with Global Warming Potential
Direct Impact/Resource Use/Waste Perspective

GWP 100 (Direct Impact/Resource Use/Waste)		Environmental Impact Criteria (Final Consumption)		All Criteria (17) (Final Consumption)	
Rank	Material/Product/Service	Rank	Change	Rank	Change
1	Electric services (utilities)	1	0	1	0
2	Crude petroleum and natural gas	4	↓2	4	↓2
3	Blast furnaces and steel mills	25	↓22	30	↓27
4	Sanitary services, steam supply, and irrigation systems	19	↓15	26	↓22
5	Air transportation	43	↓38	46	↓41
6	Petroleum refining	35	↓29	8	↓2
7	Trucking and courier services, except air	16	↓9	22	↓15
8	Feed grains	7	↑1	9	↓1
9	Meat animals	5	↑4	6	↑3
10	Coal	8	↑2	5	↑5
11	New residential 1 unit structures, nonfarm	46	↓35	10	↑1
12	Industrial inorganic and organic chemicals	3	↑9	3	↑9
13	Paper and paperboard mills	6	↑7	7	↑6
14	Fruits	24	↓10	33	↓19
15	New office, industrial and commercial buildings construction	66	↓51	23	↓8
16	Vegetables	31	↓15	38	↓22
17	Cement, hydraulic	50	↓33	53	↓36
18	Water transportation	52	↓34	60	↓42
19	Poultry and eggs	15	↑4	20	↓1
20	Wholesale trade	59	↓39	61	↓41
21	Motor vehicles and passenger car bodies	54	↓33	63	↓42
22	Water supply and sewerage systems	80	↓58	93	↓71
23	Miscellaneous plastics products, n.e.c.	47	↓24	55	↓32
24	Other new construction	71	↓47	29	↓5
25	Lime	252	↓227	86	↓61
26	Railroads and related services	37	↓11	44	↓18
27	U.S. Postal Service	197	↓170	235	↓208
28	Oil bearing crops	317	↓289	415	↓387
29	Concrete products, except block and brick	331	↓302	377	↓348
30	Plastics materials and resins	17	↑13	24	↑6
31	Iron and steel foundries	463	↓432	464	↓433
32	Motor vehicle parts and accessories	374	↓342	390	↓358
33	Food grains	11	↑22	13	↑20
34	Retail trade, except eating and drinking	72	↓38	69	↓35
35	Eating and drinking places	77	↓42	88	↓53
36	Other State and local government enterprises	357	↓321	365	↓329
37	Real estate agents, managers, operators, and lessors	426	↓389	394	↓357
38	Hospitals	435	↓397	440	↓402
39	Ready-mixed concrete	425	↓386	460	↓421
40	Dairy farm products	14	↑26	19	↑21

Table C-2
Effect of Layering Criteria on Ranking, Starting with Global Warming Potential
Intermediate Consumption Perspective

GWP 100 (Intermediate Consumption)		Environmental Impact Criteria (Final Consumption)		All Criteria (17) (Final Consumption)	
Rank	Material/Product/Service	Rank	Change	Rank	Change
1	Electric services (utilities)	1	0	1	0
2	Crude petroleum and natural gas	4	↓2	4	↓2
3	Blast furnaces and steel mills	21	↓18	17	↓14
4	Petroleum refining	11	↓7	5	↓1
5	Motor vehicles and passenger car bodies	9	↓4	12	↓7
6	Retail trade, except eating and drinking	25	↓19	22	↓16
7	Real estate agents, managers, operators, and lessors	30	↓23	18	↓11
8	New residential 1 unit structures, nonfarm	18	↓10	8	0
9	Wholesale trade	17	↓8	19	↓10
10	Eating and drinking places	13	↓3	16	↓6
11	Trucking and courier services, except air	24	↓13	25	↓14
12	Sanitary services, steam supply, and irrigation systems	37	↓25	43	↓31
13	Meat animals	5	↑8	6	↑7
14	Air transportation	64	↓50	58	↓44
15	Industrial inorganic and organic chemicals	3	↑12	3	↑12
16	Motor vehicle parts and accessories	31	↓15	35	↓19
17	New office, industrial and commercial buildings construction	35	↓18	32	↓15
18	Meat packing plants	8	↑10	11	↑7
19	Natural gas distribution	32	↓13	14	↑5
20	Hospitals	38	↓18	42	↓22
21	Miscellaneous plastics products, n.e.c.	16	↑5	21	0
22	Other new construction	50	↓28	37	↓15
23	Feed grains	12	↑11	15	↑8
24	Owner-occupied dwellings	55	↓31	38	↓14
25	Paper and paperboard mills	6	↑19	7	↑18
26	Other repair and maintenance construction	56	↓30	59	↓33
27	Coal	15	↑12	9	↑18
28	Telephone, communications, and communications services n.e.c.	66	↓38	70	↓42
29	Automotive repair shops and services	75	↓46	76	↓47
30	Banking	81	↓51	82	↓52
31	Apparel made from purchased materials	10	↑21	13	↑18
32	Computer and data processing services; including own-account software	63	↓31	69	↓37
33	Plastics materials and resins	26	↑7	30	↑3
34	Poultry slaughtering and processing	34	0	40	↓6
35	Advertising	43	↓8	46	↓11
36	Computer peripheral equipment	67	↓31	72	↓36
37	Dairy farm products	28	↑9	33	↑4
38	Poultry and eggs	33	↑5	39	↓1
39	Other electronic components	76	↓37	81	↓42
40	Water supply and sewerage systems	435	↓395	450	↓410

Table C-3
Effect of Layering Criteria on Ranking, Starting with Global Warming Potential
Final Consumption Perspective

GWP 100 (Final Consumption)		Environmental Impact Criteria (Final Consumption)		All Criteria (17) (Final Consumption)	
Rank	Material/Product/Service	Rank	Change	Rank	Change
1	Electric services (utilities)	1	0	1	0
2	Retail trade, except eating and drinking	7	↓5	6	↓4
3	Motor vehicles and passenger car bodies	3	0	4	↓1
4	Eating and drinking places	4	0	5	↓1
5	Petroleum refining	5	0	3	↑2
6	Hospitals	8	↓2	9	↓3
7	Other new construction	12	↓5	13	↓6
8	New residential 1 unit structures, nonfarm	9	↓1	8	0
9	Owner-occupied dwellings	11	↓2	11	↓2
10	Real estate agents, managers, operators, and lessors	19	↓9	18	↓8
11	Air transportation	45	↓34	38	↓27
12	Meat packing plants	6	↑6	7	↑5
13	Wholesale trade	15	↓2	15	↓2
14	New office, industrial and commercial buildings construction	17	↓3	16	↓2
15	Apparel made from purchased materials	2	↑13	2	↑13
16	Natural gas distribution	13	↑3	12	↑4
17	Banking	34	↓17	34	↓17
18	Trucking and courier services, except air	41	↓23	41	↓23
19	Automotive repair shops and services	32	↓13	32	↓13
20	New highways, bridges, and other horizontal construction	27	↓7	10	↑10
21	Poultry slaughtering and processing	14	↑7	17	↑4
22	Computer and data processing servs.; incl. own-account software	25	↓3	26	↓4
23	Doctors and dentists	30	↓7	30	↓7
24	New additions & alterations, nonfarm, construction	35	↓11	23	↑1
25	Sanitary services, steam supply, and irrigation systems	72	↓47	73	↓48
26	Water supply and sewerage systems	257	↓231	222	↓196
27	Insurance carriers	40	↓13	39	↓12
28	Telephone, telegraph communications, and communications services n.e.c.	43	↓15	43	↓15
29	Other State and local government enterprises	80	↓51	75	↓46
30	Nursing and personal care facilities	62	↓32	61	↓31
31	Other amusement and recreation services	23	↑8	25	↑6
32	Social services, n.e.c.	49	↓17	50	↓18
33	Fluid milk	18	↑15	20	↑13
34	Sausages and other prepared meat products	24	↑10	27	↑7
35	Vegetables	22	↑13	24	↑11
36	Drugs	33	↑3	35	↑1
37	Fruits	21	↑16	22	↑15
38	Bottled and canned soft drinks	50	↓12	51	↓13
39	Electronic computers	54	↓15	56	↓17
40	Automotive rental and leasing, without drivers	70	↓30	68	↓28

