Comparison of Environmental Burdens

Recycling, Disposal with Energy Recovery from Landfill Gases, and Disposal via Hypothetical Waste-to-Energy Incineration

San Luis Obispo County 2002

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Prepared for
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San Luis Obispo, California

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The San Luis Obispo County Integrated Waste Management Authority (IWMA) contracted with Sound Resource Management (SRMG) to conduct a life cycle analysis of important and quantifiable environmental impacts associated with the County's curbside/on site refuse collection and disposal, and curbside recycling systems. The IWMA also asked SRMG to evaluate those same environmental impacts that would be associated with disposal of collected refuse in a waste-to-energy incineration facility rather than the County's current landfill where landfill gas (LFG) is collected and used for energy generation. The following report provides the results of SRMG's analysis.

I. Background and Summary Conclusions

A. Background

SRMG used life cycle assessment (LCA) techniques to enumerate and evaluate important and quantifiable environmental burdens associated with collection and management of municipal solid waste in SLO County during 2002. The particular environmental burdens we evaluated were:

- Energy usage,
- Increases in global warming, acidification and eutrophication potentials associated with emissions of certain pollutants to the atmosphere and to waterways,
- Increases in potential adverse impacts on human health associated with criteria air pollutant emissions and with releases of toxic substances to the atmosphere and to waterways, and
- Increases in potential adverse impacts on ecological systems associated with releases of toxic substances to the atmosphere and to waterways.

We compared these environmental burdens caused by curbside collection for recycling, processing, and market shipment of recyclable materials picked up from households and businesses against those same type of environmental burdens caused by curbside collection and disposal of mixed solid waste in the Cold Canyon landfill where landfill gas is collected and used for energy generation. We also evaluated the likely extent of these environmental burdens from disposal of refuse in a hypothetical waste-to-energy (WTE) incineration facility rather than disposal in the current landfill with LFG energy recovery.

For this project SRMG used life cycle inventory (LCI) techniques to estimate atmospheric emissions of ten pollutants, waterborne emissions of seventeen pollutants, and emissions of industrial solid waste associated with curbside recycling, as well as refuse collection and disposal methods for managing municipal solid waste. We also estimated total energy consumption for the recycling versus disposal methods of managing SLO County's municipal solid wastes.

Emissions estimates came from the Decision Support Tool (DST) developed for assessing the cost and environmental burdens of integrated solid waste management strategies by North Carolina State University (NCSU) in conjunction with Research Triangle Institute (RTI) and the US Environmental Protection Agency (US EPA),[1] as well as from the Municipal Solid Waste Life-Cycle Database (Database), prepared by RTI with the support of US EPA during DST model development, to estimate environmental emissions from solid waste management practices.[2]

Once we developed the LCI estimates, SRMG then prepared a life cycle environmental impacts assessment of the environmental burdens associated with these emissions. To do this we used the Envi-

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[1] (RTI 1999a), (RTI 1999b), (Barlaz 2003a), and (Barlaz 2003b).

[2] Both the DST and its Database are intended to be available for sale to the public by RTI. Contact Keith Weitz at kaw@rti.org for further information on public release dates for the DST and the Database.

ronmental Problems approach discussed in the methodology section of this report. This approach combines the LCI detail on emissions estimates for individual pollutants into aggregate measures of potential impacts caused by certain categories of pollutant emissions. For example, emissions of carbon dioxide, methane, nitrous oxide and CFC/HFCs are weighted according to each pollutant's potency for trapping heat in the atmosphere (the greenhouse effect) relative to the heat trapping potency of carbon dioxide. This calculation yields an index of global warming potential that is expressed as pounds (or tons) of carbon dioxide releases which have the same global warming potential as the combined releases of the individual greenhouse gases.

B. Summary Conclusions

Recycling of newspaper, cardboard, mixed paper, glass bottles and jars, aluminum cans, tin-plated steel cans, plastic bottles, and other conventionally recoverable materials found in household and business municipal solid wastes in general consumes less energy and imposes lower environmental burdens than disposal of solid waste materials via landfilling or incineration, even after accounting for energy that may be recovered from waste materials at either type disposal facility. This result holds for all environmental impacts evaluated in this study:

- Global warming,
- Acidification,
- Eutrophication,
- Disability adjusted life year (DALY) losses from emissions of criteria air pollutants,
- Human toxicity, and
- Ecological toxicity.

The basic reason for the general conclusion that recycling uses less energy and causes lower environmental burdens than either disposal method is that there is a substantial amount of energy conservation and pollution prevention engendered by using recycled rather than virgin materials as feedstocks for manufacturing new products. These energy conservation and pollution reductions from recycled-content manufacturing tend to be an order of magnitude greater than the additional energy and environmental burdens imposed by curbside collection trucks, recycled material processing facilities, and transportation of processed recyclables to end-use markets.

Furthermore, the energy grid offsets and associated reductions in environmental burdens yielded by generation of energy from landfill gas or from mixed solid waste combustion are substantially smaller then the upstream energy and pollution offsets attained by manufacturing products with recycled materials. This is true even after accounting for energy used and pollutants emitted during collection, processing and transportation to end-use markets for recycled materials.

The remaining portions of this Summary Conclusions section of our report review graphical results for our comparative analysis. The graphs show the increases in energy usage and environmental pollution that would result if the County were to abandon its curbside and on-site recycling collections, and instead send all solid waste materials to the Cold Canyon Landfill or to a hypothetical waste-to-energy (WTE) facility.

Details for comparisons between recycling and landfilling are provided in Appendix A, and in Appendix B for recycling versus WTE incineration. These appendices show impacts for each component of the recycling and disposal waste management systems, so that the interested reader can compare impacts of, for example, collection trucks versus recyclables processing or virgin materials offsets versus energy grid offsets.

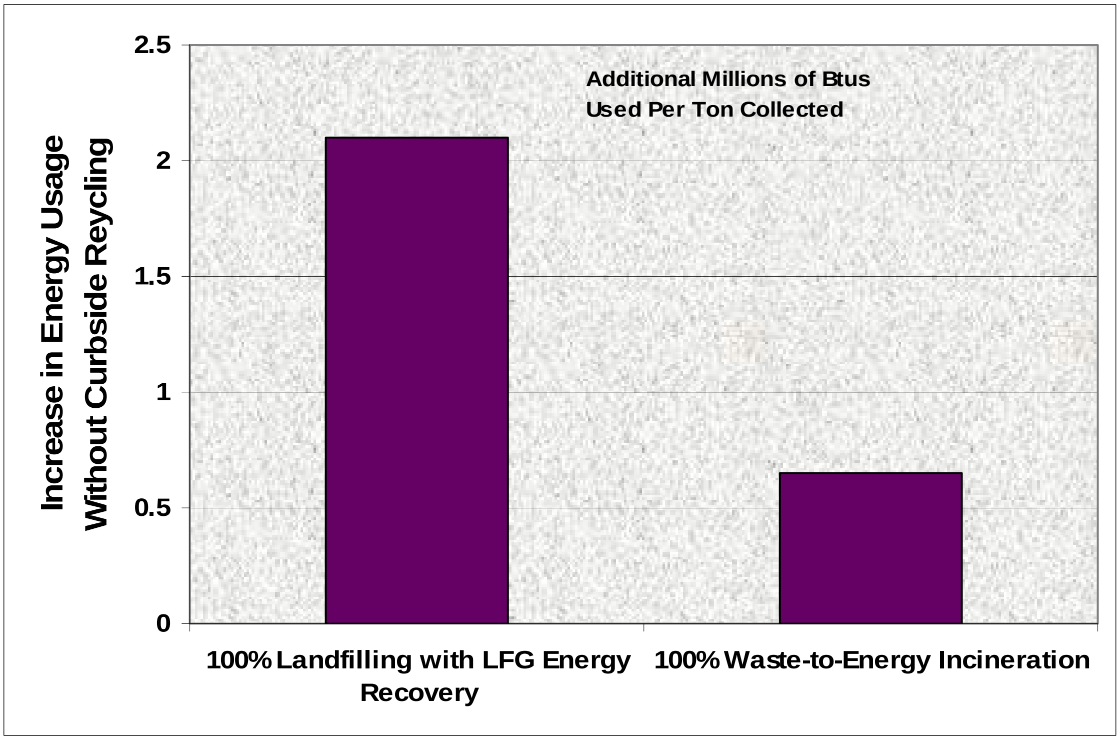
1. Energy Conservation from Curbside/On-Site Recycling

Figure 1, Incremental Energy Usage by 100% Landfilling or 100% WTE System, shows the amount of additional energy that would be used per ton of solid waste material collected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental energy usage per ton if all collected refuse and recyclables were delivered to a WTE incineration facility instead of recyclables being delivered, as at present, to the Cold Canyon recyclables processing facility and currently collected refuse being delivered to the hypothetical WTE facility.[3]

As indicated in Figure 1, the 100% landfilling waste management system would use 2.1 million BTUs more energy per ton collected than the current system which entails curbside/onsite collection of recyclables, along with collection and landfill disposal with LFG energy recovery for refuse. Similarly, 100% WTE incineration likely would use over 0.6 million additional BTUs per ton compared with the mixed system of current curbside/onsite recycling and disposal via WTE incineration instead of landfilling. Thus, while 100% WTE incineration uses less energy than 100% landfilling, curbside recycling still saves more energy on every ton collected for recycling instead of incineration.

Figure 1

Incremental Energy Usage by 100% Landfilling or 100% WTE System



2. Reductions in Global Warming Potential from Curbside/On-Site Recycling

Figure 2, Incremental Greenhouse Gas Releases by 100% Landfilling or 100% WTE System, shows the amount of additional greenhouse gases that would be released per ton of solid waste material col-

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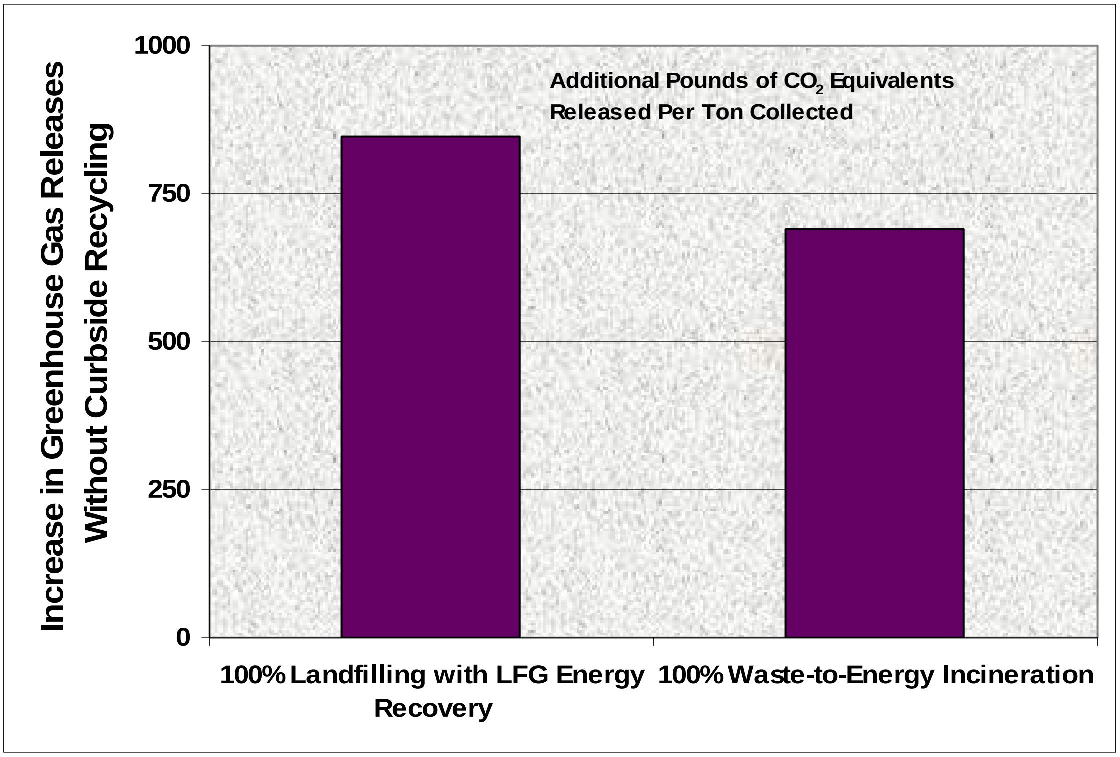
[3] The assumption used to calculate incremental energy usage for the 100% WTE System is that the hypothetical WTE facility is located at the same site as the Cold Canyon landfill. This assumption means that travel distance from the end of a refuse collection route to the disposal facility is the same for both landfill and incineration disposal facilities.

lected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental greenhouse gas releases per ton if all collected refuse and recyclables were delivered to a WTE incineration facility.

As indicated in Figure 2, the 100% landfilling waste management system would release nearly 850 pounds more greenhouse gases per ton collected than the current system which entails curbside/onsite collection of recyclables, along with collection and landfill disposal with LFG energy recovery for refuse. Similarly, 100% WTE incineration likely would release nearly 700 additional pounds of greenhouse gases per ton collected compared with the hypothetical mixed system of current recycling with disposal via WTE incineration instead of landfilling. Thus, both 100% landfilling and 100% WTE incineration release substantially more greenhouse gases than a system that includes curbside and on-site recycling collections. This is because curbside recycling reduces greenhouse gases on every ton collected for recycling instead of disposal by either landfilling or incineration with energy recovery.

Figure 2

Incremental Greenhouse Gas Releases by 100% Landfilling or 100% WTE System



3. Reductions in Acidification Potential from Curbside/On-Site Recycling

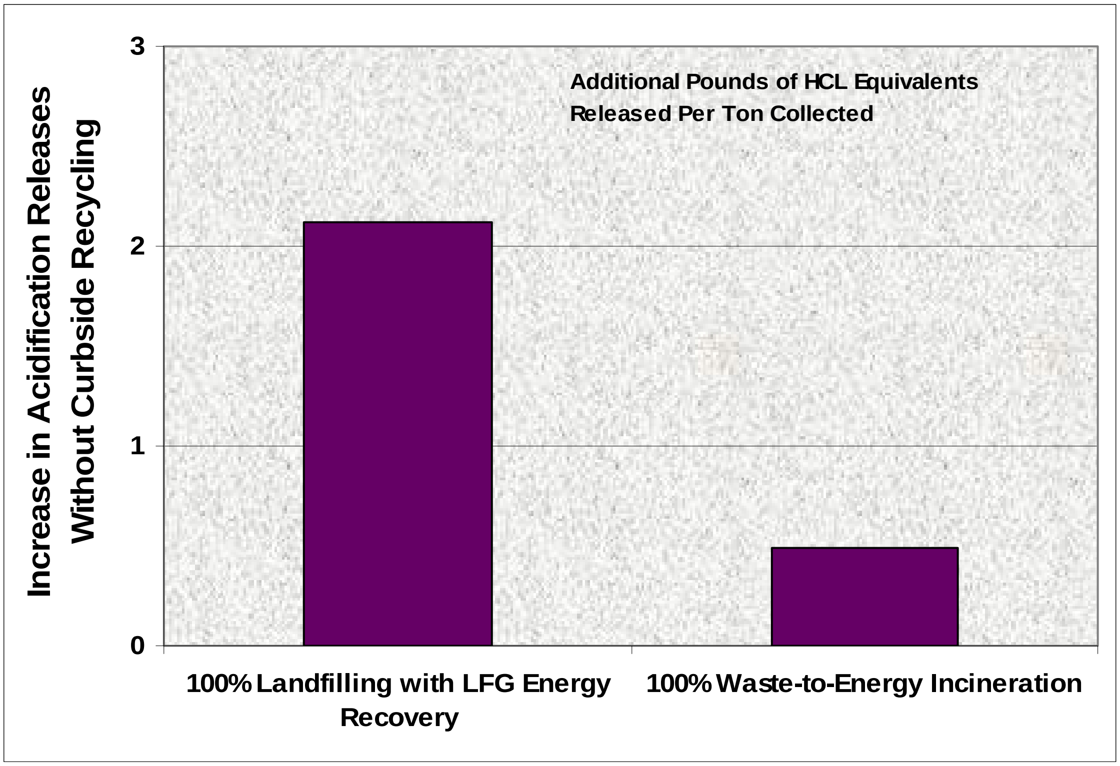
Figure 3, Incremental Acidification Potential Increases by 100% Landfilling or 100% WTE System, shows the amount of additional acidification potential from releases of acidifying compounds per ton of solid waste material collected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental acidification potential increases per ton if all collected refuse and recyclables were delivered to a WTE incineration facility.

Release of acidifying compounds from human sources, principally fossil fuel and biomass combustion, affects trees, soil, buildings, animals and humans. The main pollutants involved in acidification are sulfur and nitrogen compounds – e.g., sulfur oxides, sulfuric acid, nitrogen oxides, hydrochloric acid (HCL), and ammonia.

As indicated in Figure 3, the 100% landfilling waste management system would release over two pounds more hydrochloric acid equivalents per ton collected than the current system which entails curbside/onsite collection of recyclables, along with collection and landfill disposal with LFG energy recovery for refuse. Similarly, 100% WTE incineration likely would release an additional half pound of hydrochloric acid equivalents per ton collected compared with the hypothetical mixed system of recycling and WTE disposal. Thus, while 100% WTE incineration releases less acidifying compounds than 100% landfilling, curbside recycling still prevents releases of acidifying compounds on every ton collected for recycling instead of incineration.

Figure 3

Incremental Acidification Potential Increases by 100% Landfilling or 100% WTE System



4. Reductions in Eutrophication Potential from Curbside/On-Site Recycling

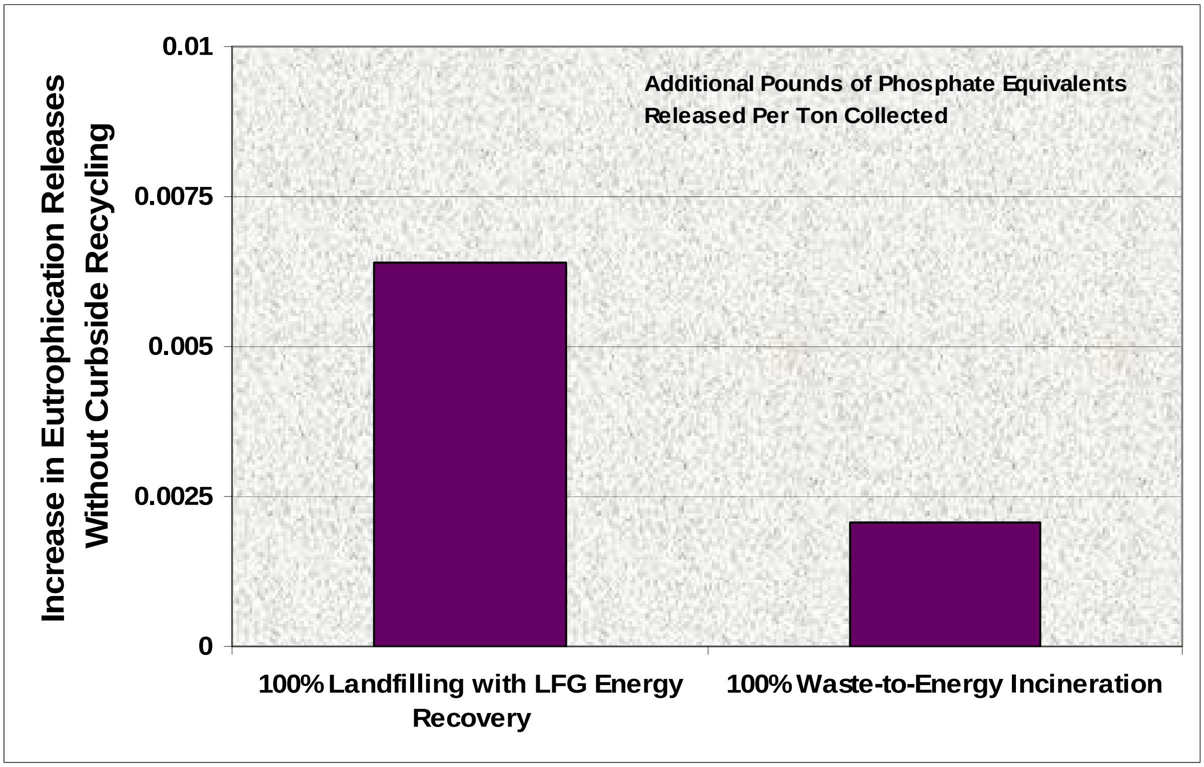
Figure 4, Incremental Eutrophication Potential Increases by 100% Landfilling or 100% WTE System, shows the amount of additional eutrophication potential from releases of nutrifying compounds per ton of solid waste material collected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental eutrophication potential increases per ton if all collected refuse and recyclables were delivered to a WTE incineration facility instead of recyclables going to the Cold Canyon recycling processing facility and refuse going to the hypothetical WTE incineration facility.

"Eutrophication is the addition of mineral nutrients to the soil or water. In both media, the addition of large quantities of mineral nutrients, such as nitrogen and phosphorous, results in generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, it tends to increase algae growth, which can lead to lack of oxygen and therefore death of species like fish."[4]

As indicated in Figure 4, the 100% landfilling waste management system would release more phosphate equivalents per ton collected than the current system which entails curbside/onsite collection of recyclables, along with collection and landfill disposal with LFG energy recovery for refuse. Similarly, 100% WTE incineration also would release additional phosphate equivalents per ton collected compared with the hypothetical mixed system of recycling and WTE disposal. Thus, while 100% WTE incineration releases less nutrifying compounds than 100% landfilling, curbside recycling still provides even greater prevention of nutrifying releases on every ton collected for recycling instead of incineration.

Figure 4

Incremental Eutrophication Potential Increases by 100% Landfilling or 100% WTE System



5. Reductions in DALY Losses from Curbside/On-Site Recycling

Figure 5, Incremental DALY Loss Increases by 100% Landfilling or 100% WTE System, shows the shows the additional microDALY losses from releases of criteria air pollutants per ton of solid waste material collected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental microDALY loss increases per ton if all collected refuse and recyclables were delivered to a WTE incineration facility.

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[4] BEES 3.0 Manual (Lippiatt 2002), p. 13.

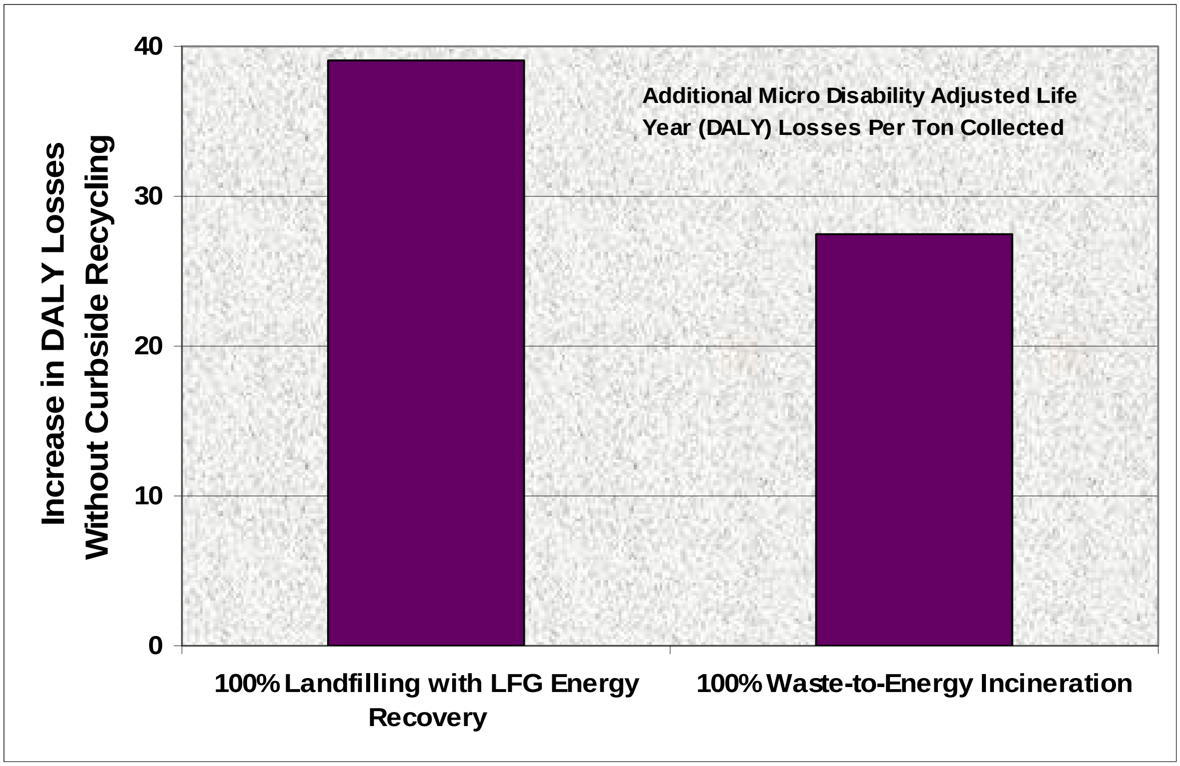
"Criteria air pollutants are solid and liquid particles commonly found in the air….They include coarse particles known to aggravate respiratory conditions such as asthma, and fine particles that can lead to more serious respiratory symptoms and disease."[5] In particular, air emissions included in the criteria air pollutants category are nitrogen oxides, sulfur oxides, and particulates both larger and smaller than 2.5 microns.

"Disability-adjusted life years, or DALYs, have been developed to measure health losses from air pollution. They account for years of life lost and years lived with disability, adjusted for the severity of the associated unfavorable health conditions."[6]

As indicated in Figure 5, the 100% landfilling waste management system would incur 39 additional microDALY losses per ton collected versus the current system which entails curbside/onsite collection of recyclables, along with refuse collection and landfill disposal with LFG energy recovery. The 100% WTE incineration system would incur 27.5 additional microDALY losses. Thus, both 100% landfilling and 100% WTE incineration cause additional DALY losses due to greater releases of criteria air pollutants than does the waste management system that includes curbside and on-site recycling collections in addition to refuse disposal via landfilling or incineration.

Figure 5

Incremental DALY Loss Increases by 100% Landfilling or 100% WTE System



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[5] Bees 3.0 Manual, *op. cit.*, p. 18

[6] *Ibid*, p. 18

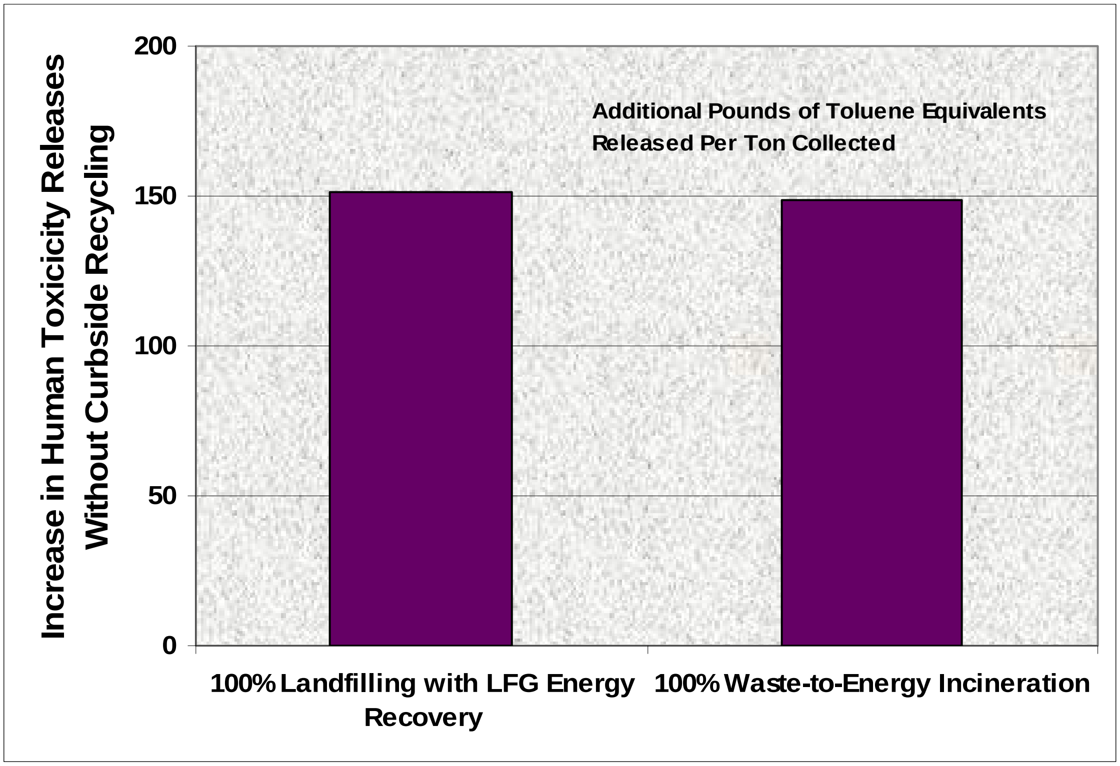
6. Reductions in Human Toxicity Potential from Curbside/On-Site Recycling

Figure 6, Incremental Human Toxicity Potential Increases by 100% Landfilling or 100% WTE System, shows the estimated increase in human toxicity potential from releases of toxic compounds per ton of solid waste material collected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental human toxicity potential increases per ton if all collected refuse and recyclables were delivered to a WTE incineration facility. Appendix A provides details on the methodology behind the human toxicity potential index measurements reported in Figure 6.

As indicated in Figure 6, the 100% landfilling waste management system would release more emissions to air and water that are potentially toxic to humans, estimated at 151 pounds of toluene equivalents, per ton collected than the current system which entails curbside/onsite collection of recyclables, along with collection and landfill disposal with LFG energy recovery for refuse. Similarly, 100% WTE incineration likely would release an additional 149 pounds of toluene equivalents per ton collected compared with the hypothetical system in which recyclables go to the Cold Canyon recycling processing facility, as they currently do, and refuse goes to the hypothetical WTE incineration facility. Thus, both 100% landfilling and 100% WTE incineration release substantially more air and water pollutants that are potentially toxic to humans than the mixed system that includes curbside and on-site recycling collections.

Figure 6

Incremental Human Toxicity Potential Increases by 100% Landfilling or 100% WTE System



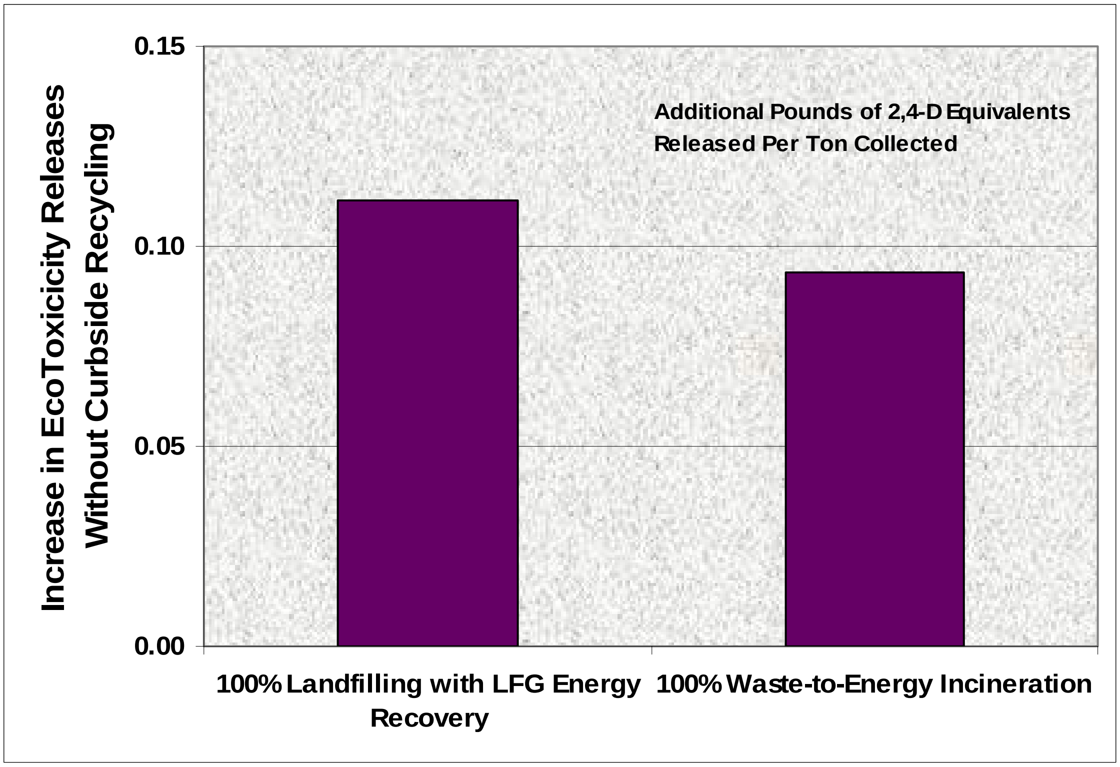
7. Reductions in Ecological Toxicity Potential from Curbside/On-Site Recycling

Figure 7, Incremental Ecological Toxicity Potential Increases by 100% Landfilling or 100% WTE System, shows the estimated increase in ecological toxicity potential from releases of toxic compounds per ton of solid waste material collected if SLO County abandoned its curbside recycling system in favor of 100% landfilling with LFG energy recovery. The chart also shows hypothetical incremental ecotoxicity potential increases per ton if all collected refuse and recyclables were delivered to a WTE incineration facility. Appendix A provides details on the methodology behind the ecological toxicity potential index measurements reported in Figure 7.

As indicated in Figure 7, the 100% landfilling waste management system would release more emissions to air and water that are potentially toxic to ecosystems, estimated at .11 pounds of 2,4-D equivalents, per ton collected than the current system which entails curbside/onsite collection of recyclables, along with collection and landfill disposal with LFG energy recovery for refuse. Similarly, 100% WTE incineration likely would release an additional .09 pounds of 2,4-D equivalents per ton collected compared with the hypothetical mixed system that includes current curbside/on-site recycling along with WTE incineration only for currently collected refuse. Thus, both 100% landfilling and 100% WTE incineration release more air and water pollutants that are potentially toxic to ecosystems than a mixed system that includes curbside and on-site recycling collections.

Figure 7

Incremental Ecological Toxicity Potential Increases by 100% Landfilling or 100% WTE System



II. Brief History on Development of the DST and its Associated Database

Industry and governmental agencies have been tracking emissions of certain pollutants to the air and water for a number of years. During the past fifteen years researchers began to use these data along with other information to prepare life-cycle inventory (LCI) studies on solid waste management systems that handle the materials generated as residuals (i.e., discards or wastes) from production and consumption activities. These LCI studies examined the life cycle of products, beginning with the acquisition from natural ecosystems of raw materials used for manufacturing a product, all the way through to management of discards at the end of the product's life. This was done to determine material and energy inputs and waste outputs and environmental releases associated with production, use and end-of-life management of that product.

Over the past ten years RTI has been managing a project, with extensive financial and in-kind support from US EPA and with assistance from NCSU, to develop the DST to model municipal solid waste management systems in an optimizing framework. A significant goal of the project was to create a model and database that could assist local communities, as well as others involved in handling solid wastes and managing facilities, in their quest to find waste management systems that achieve and/or balance the twin goals of being cost-effective and minimizing environmental impacts. The structural equations and emissions data that are contained in the DST and its Database have been informed by an extensive peer and multi-stakeholder review process conducted by US EPA and RTI.

As with any intellectual inquiry there remain several serious substantive debates regarding assumptions and default parameters in the DST – e.g., the modeling of landfill liner failure and the capture efficiency for landfill gas collection systems. In addition, the number of pollutant emissions tracked by the DST model is quite small in comparison to the actual number of chemical substances used and emitted during resource extraction and refining, product manufacturing and product end-of-life management. Thus there remain some very important pollutants and toxins whose emissions are not tracked in the DST – for example, atmospheric emissions of mercury and dioxins. Despite these shortcomings, the DST and its associated Database provide very thoroughly reviewed and relatively comprehensive tools for quantification of many significant environmental burdens associated with using the wide variety of methods available for managing municipal solid wastes.

III. Methodology for SLO IWMA

The methodology used to estimate and evaluate emissions associated with SLO County's solid waste management system included four distinct steps:

(1) Data Collection: The IWMA provided information to SRMG on quantities of recyclables and refuse collected curbside in the large contiguous southern portion of the county serviced by the Cold Canyon collection companies. The IWMA also provided data on the quantities of each type of processed material sold to recycling end-use markets, and data on the separate quantities of diesel consumed for curbside/on-site recycling and curbside/on-site refuse collections from households and businesses.

(2) Preparation of Data for Analysis: SRMG augmented IWMA information on collection quantities, processing quantities, landfill quantities and diesel usage for collection with estimates of the energy usage and environmental burdens from production of collection vehicles. These estimates came from Carnegie-Mellon's Green design Initiative Economic Input-Output Life Cycle Assessment (EIO-LCA) model.[7]

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[7] This model is available on the Internet at www.eiolca.net. The EIO-LCA model attaches a matrix of energy usage and pollutant emissions for each industry to an input-output model of the US economy in order to compute a life cycle inventory for products produced by each industry.

(3) Life Cycle Inventory (LCI) Calculations: SRMG used the DST Database to calculate energy usage and pollutant emissions associated with curbside/on-site collection of recyclables and curbside/on-site collection of refuse. Furthermore, at the time of this study RTI had not fully incorporated into the DST and Database complete estimates of the global warming benefits from carbon sequestration in forests due to recycling of paper. To compensate for this lack, SRMG used US EPA's WARM model to include carbon sequestration in forests in the calculation of upstream energy conservation and pollution prevention benefits from paper recycling.[8]

(4) Life Cycle Environmental Impacts Assessment: SRMG used the Environmental Problems approach to impact assessment as developed in the early 1990s within the Society for Environmental Toxicology and Chemistry (SETAC). This approach is codified in the National Institute of Standards and Technology's Building for Environmental and Economic Sustainability (BEES) 3.0 model (Lippiatt 2002), and supported by US EPA Office of Research and Development's recent development of TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts).[9] SRMG assessed six environmental impacts using the BEES codifications – global warming potential, acidification potential, eutrophication potential, human health impacts from releases of criteria air pollutants, human health impacts from toxic releases, and ecological impacts from toxic releases.

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[8] WARM is available on the Internet at www.epa.gov/globalwarming/actions/waste/warm.htm . See (USEPA 2002a) for the methodology and research that supports this model.

[9] TRACI is a set of state-of-the-art, peer-reviewed US life cycle impact assessment methods. See (US EPA 2002b) and (Bare 2002). The BEES weights for assembling pollutant emissions into impact categories are given in the BEES 3.0 manual (Lippiatt 2002).

IV. Appendix A – Detail on Results for Recycling Vs. Landfilling

During 2002 the Cold Canyon companies collected 24,261 tons of recyclables and 104,926 tons of refuse in their service areas. These collection areas comprise the southern part of San Luis Obispo County and include a very large portion of the households and businesses in that county. The composition of collected recyclables was approximately 40.4% mixed and office paper, 20.6% glass, 16.5% cardboard, 15.7% newspapers, 4.1% plastic, 2.1% steel and 0.6% aluminum. Due to a lack of composition data for SLO County refuse, SRMG used the DST's default national average waste composition profile to characterize collected refuse.

A. Energy Savings from Recycling Compared with Landfilling

Figure A-1, Comparative Energy Usage for Recycling vs. Landfilling, shows estimated energy used in 2002 for collecting recyclables and refuse, and delivering those respective quantities to processing and landfill facilities. Figure A-1 also shows estimated energy used in 2002 for operating the landfill, processing and shipping recyclables to end-use markets, and manufacturing processed recyclables into new products. Energy usages for these components of SLO County's recycling and disposal systems are shown as positive (upward pointing from the zero axis) portions of the respective stacked bars for Recycling Impacts and Garbage Impacts in Figure A-1.

The energy conserved from recycling, as a result of avoiding the manufacture of new products from virgin raw materials, is shown as the bright green negative (downward pointing from the zero axis) portion of the stacked bar for Recycling Impacts. Producing products such as newsprint, cardboard, glass containers, aluminum can sheet and plastic pellets with virgin materials requires 23.3 million Btus, compared with the 10.4 million Btus, or 45% as much energy, needed to make this same quantity and mix of products with the recycled material components that were, on average, in each ton of materials collected for recycling from SLO County households and businesses during 2002.

Figure A-2, Comparative Energy Usage for Recycled- Vs. Virgin-Content Products, shows these energy savings for the closed-loop, recycled-content manufactured products which can use SLO's recycled materials as feedstocks. As indicated in Figure A-2, recycled-content products require much less energy than virgin-content products. Recycled-content aluminum sheet and plastic pellets require between 5% and 7% of the energy needed to make these items from virgin raw materials. Recycled-content steel requires about 37% of the energy required for virgin steel. Recycled-content newsprint and cardboard use less than half the energy required for virgin. Even recycled-content glass containers only require 65% of the energy needed to produce virgin-content glass jars.

Given the mix of paper, plastic, metal and glass materials recycled in SLO County, these estimated energy savings for individual recycled-content products yield the estimate that producing products with SLO's recycled materials uses only 45% as much energy as would be required to produce that same mix of products with virgin feedstocks. Thus, as shown by the dark blue Net Recycling Impact bar in Figure A-1, recycling saves 12 million Btus per ton recycled. As also shown in Figure A-1, these upstream energy savings from recycling are an order of magnitude larger than the estimated 0.9 million Btus needed to collect, process and ship to market the recyclables collected in SLO County's curbside/on-site recycling programs.

Figure A-1

Comparative Energy Usage for SLO Recycling vs. Landfilling

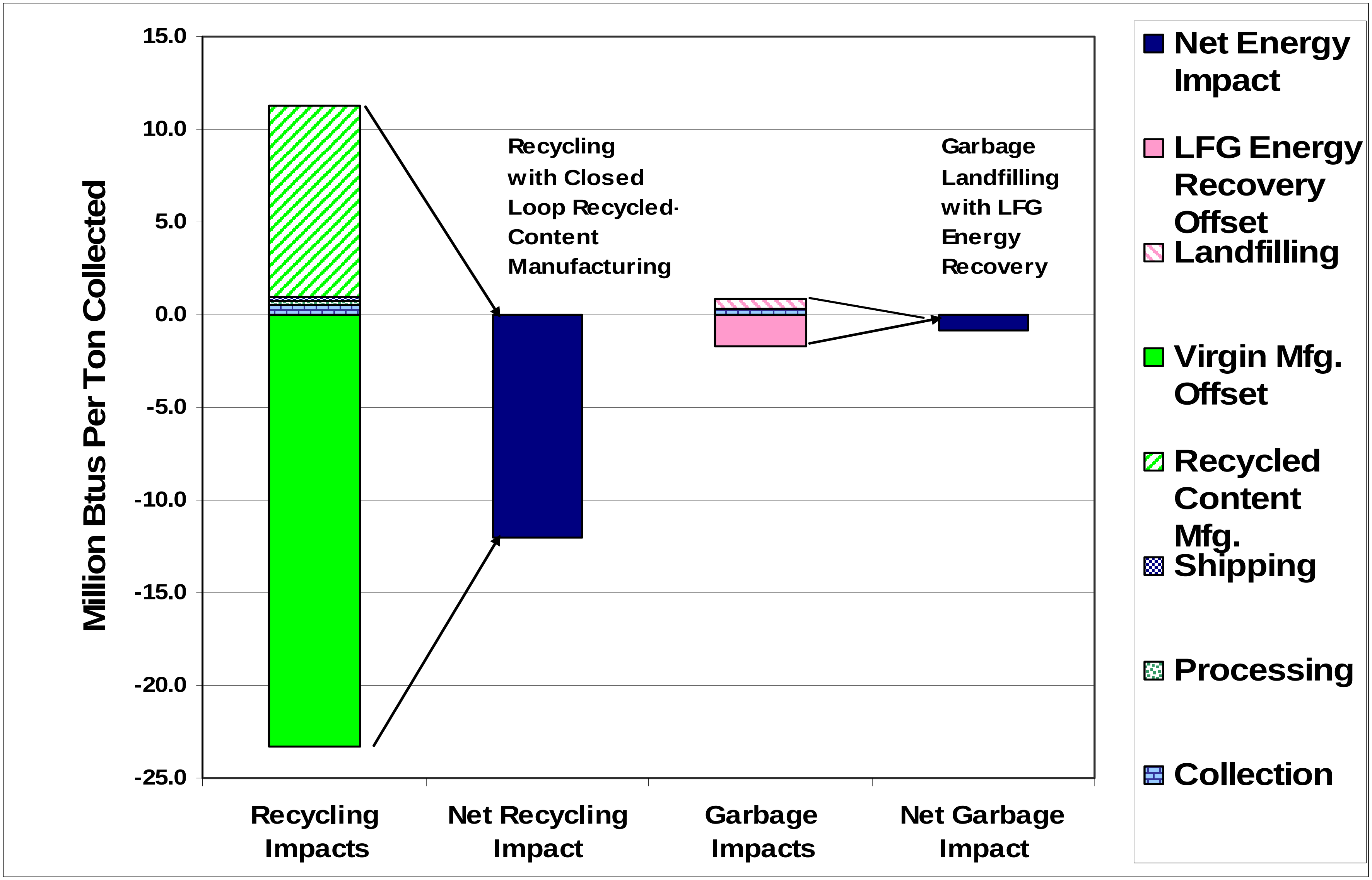
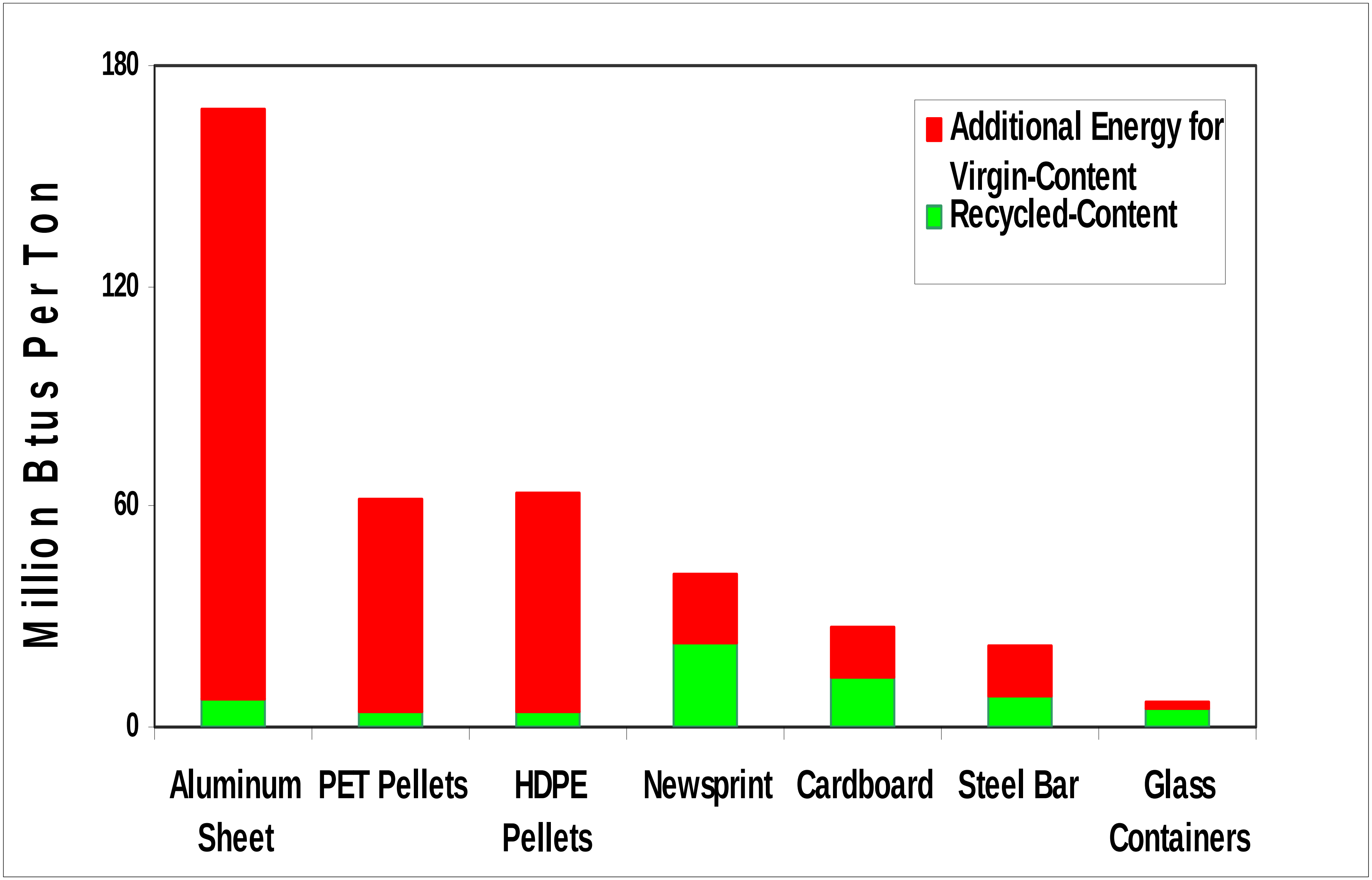


Figure A-2

Comparative Energy Usage for Recycled- Vs. Virgin-Content Products



Estimated energy generated from landfill gas (LFG) collected at the Cold Canyon landfill is also shown in Figure A-1 as a negative offset to the estimated energy required to collect and landfill refuse. As indicated in Figure A-1, the energy offset from LFG, estimated at 1.7 million Btus per ton of collected refuse, is greater than the estimated total energy of 0.8 million Btus required for collecting and landfilling refuse.

This portrayal of SLO County's refuse management system flows from the structural equations and assumptions in the DST that model how each ton of refuse deposited in a landfill with a LFG collection system will anaerobically decompose over time, and how effectively the LFG collection system captures methane and other volatile gases released during that decomposition process. The defaults used in the DST, and thus in the calculations for Figure A-1, assume that landfill gases will be captured at greater than a 75% efficiency rate by the LFG collection system. Consequently, the DST estimates that each ton of refuse landfilled at SLO County's Cold Canyon landfill yields a reduction in global energy demand of 0.9 million Btus over the time period required for biodegradation of that refuse, as indicated by the dark blue bar for Net Garbage Impact in Figure A-1.

As previously discussed, there is an ongoing substantive debate regarding capture efficiencies for LFG collection systems. But even without lowering the assumed capture rate down from 75%, recycling in SLO County is over thirteen times more effective at reducing global energy demand than landfilling with LFG energy recovery. Thus, one would need to look at cost-effectiveness of recycling versus landfilling, recyclability of the materials remaining in refuse, or some other criterion besides energy efficiency to find a reason for not maximizing separation of recyclable materials from refuse so that they can be recovered for use in manufacturing recycled-content products.

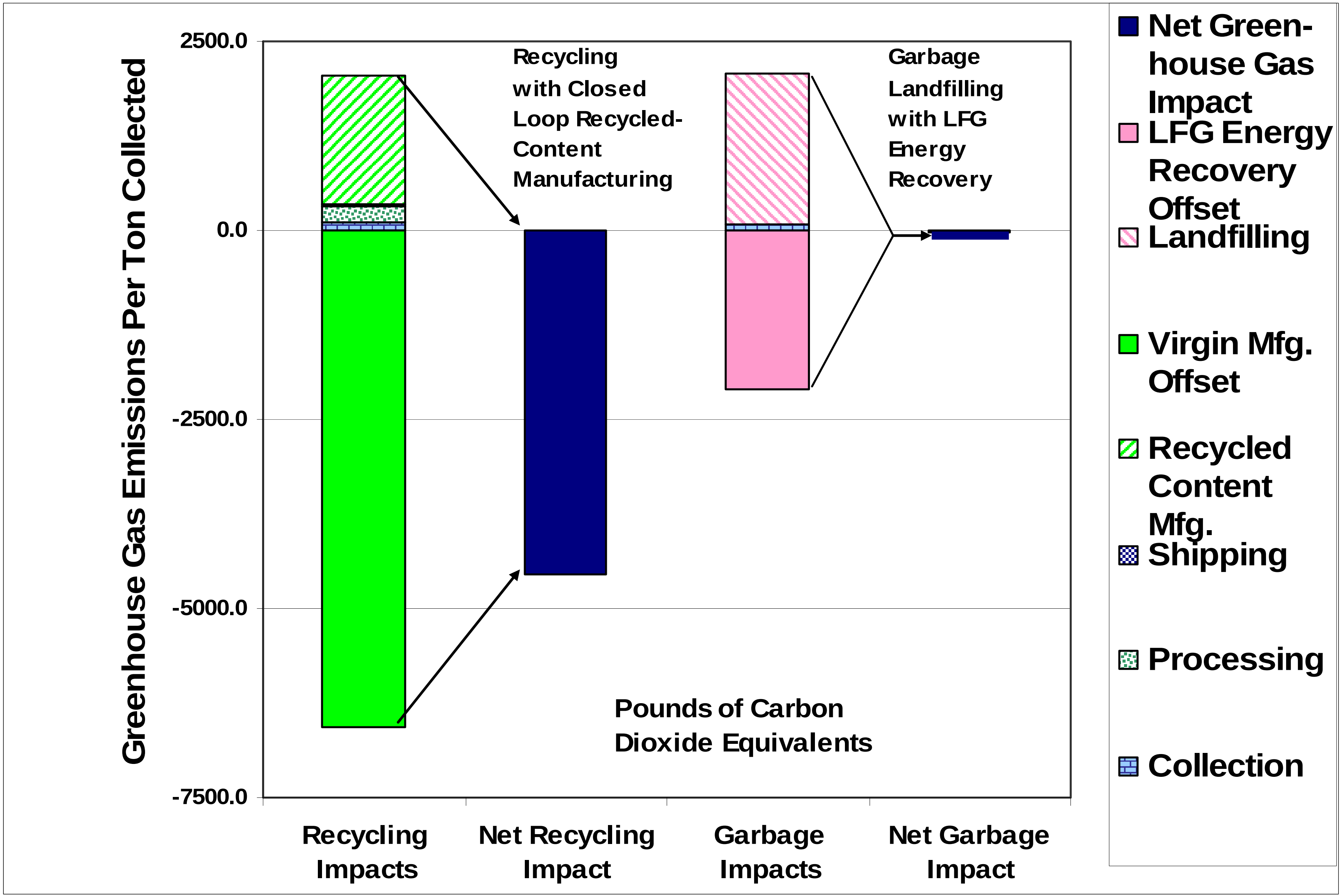
B. Greenhouse Gas Reductions from Recycling Compared with Landfilling

Figure A-3, Comparative Greenhouse Gas Emissions for SLO Recycling vs. Landfilling, shows estimated emissions of greenhouse gases in 2002 from collecting recyclables and refuse, and delivering those respective quantities to processing and landfill facilities. Figure A-3 also shows estimated greenhouse gas emissions during 2002 from operating the landfill, processing and shipping recyclables to end-use markets, and manufacturing processed recyclables into new products. Greenhouse gas emissions for these components of SLO County's recycling and disposal systems are shown as positive portions of the respective stacked bars for Recycling Impacts and Garbage Impacts in Figure A-3.

Greenhouse gas emission offsets from recycling, as a result of avoiding the manufacture of new products from virgin raw materials, are shown as the bright green negative portion of the stacked bar for Recycling Impacts. Producing products such as newsprint, cardboard, glass containers, aluminum can sheet and plastic pellets with virgin materials emits 6,577 pounds of carbon dioxide equivalents, compared with the 1,685 pounds emitted to manufacture this same quantity and mix of products with the recycled materials components that were, on average, in each ton of materials collected for recycling from SLO households and businesses during 2002. That is, using materials recycled in SLO County during 2002 to manufacture new products reduced greenhouse gas emissions to a level that is just 26% of the quantity of carbon dioxide equivalents that would have been emitted to make this same quantity and mix of new products from virgin raw materials.

Figure A-3

Comparative Greenhouse Gas Emissions for SLO Recycling vs. Landfilling



Estimated greenhouse gas offsets for energy generated from landfill gases collected at SLO's landfill in 2002 are shown as the bright pink negative portion of the Garbage Impacts stacked bar. These reductions in greenhouse gases that would otherwise have been generated at coal fired power plants to produce the energy generated by SLO's collected landfill gas were substantial enough, given the greater than 75% capture efficiency assumed for the landfill's gas collection system, to more than offset the combined greenhouse effects of methane emissions from gases that escape the landfill's gas collection system and carbon dioxide emissions from diesel fuels consumed in collecting refuse, hauling it to the landfill, and compacting it in place at the landfill.

The Net Garbage Impact bar in Figure A-3 indicates that collecting landfill gases to generate energy reduces global greenhouse gas emissions by 23.4 pounds of carbon dioxide equivalents per ton of collected refuse. Recycling, on the other hand, reduces greenhouse gas emissions by 4,537.3 pounds for each ton of collected recyclables according to the Net Recycling Impact bar shown in Figure A-3. On this basis recycling is 194 times more effective per ton of material handled than landfilling in terms of reducing global greenhouse gas emissions. Furthermore, the greenhouse gas impacts from collecting, processing and shipping recycled materials to market are more than an order of magnitude smaller than the upstream prevention of greenhouse gas emissions achieved by using recycled rather than virgin materials to manufacture new products.

C. Acidification and Eutrophication Potential Reductions from Recycling Compared with Landfilling

As Figure A-3 did for greenhouse gases, Figures A-4, Comparative Acidification Potential Emissions for SLO Recycling vs. Landfilling, and A-5, Comparative Eutrophication Potential Emissions for SLO Recycling vs. Landfilling, show the same advantages over landfilling, even with energy recovery from captured landfill gases, for collecting recyclables, processing them, and shipping them to end users where they are used instead of virgin materials in manufacturing new products. In these figures the potentials for environmental damages indexed on the bar graphs are impacts from the release of acidifying and nutrifying compounds into the atmosphere and waterways.

As indicated in Figures A-4 and A-5, recycling is five times more effective than landfilling at reducing emissions of acidifying substances that cause such environmental burdens as acid rain, and eighteen times more effective at reducing emissions of eutrophying substances that cause environmental damages such as nutrification of lakes and streams. Also, the environmental burdens for these two impact categories imposed by collection, processing and shipping recycled materials to end users are again quite small compared with the environmental burdens avoided when recycled materials replace virgin raw materials as input feedstock for manufacturing new products.

Figure A-4

Comparative Acidification Potential Emissions for SLO Recycling vs. Landfilling

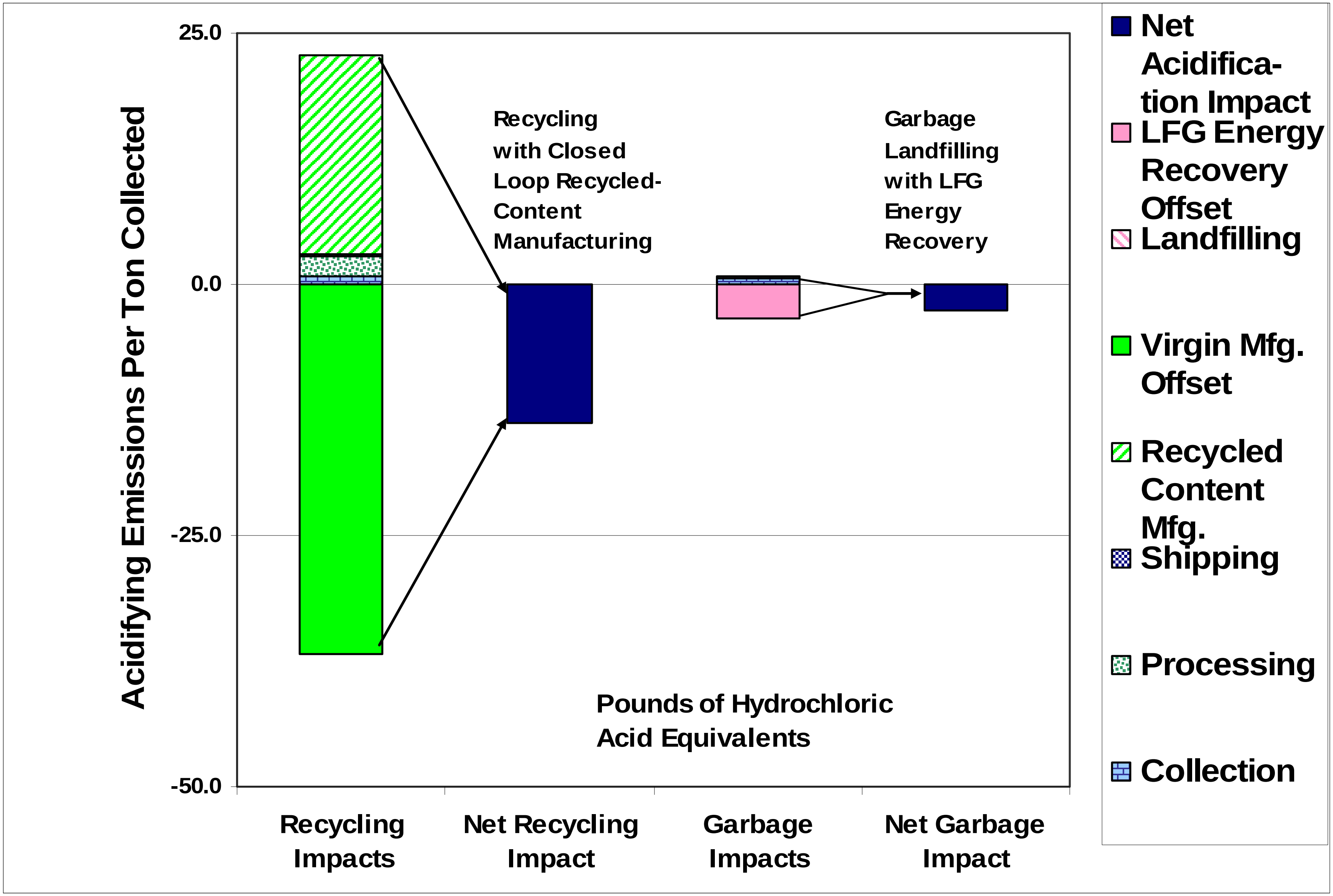
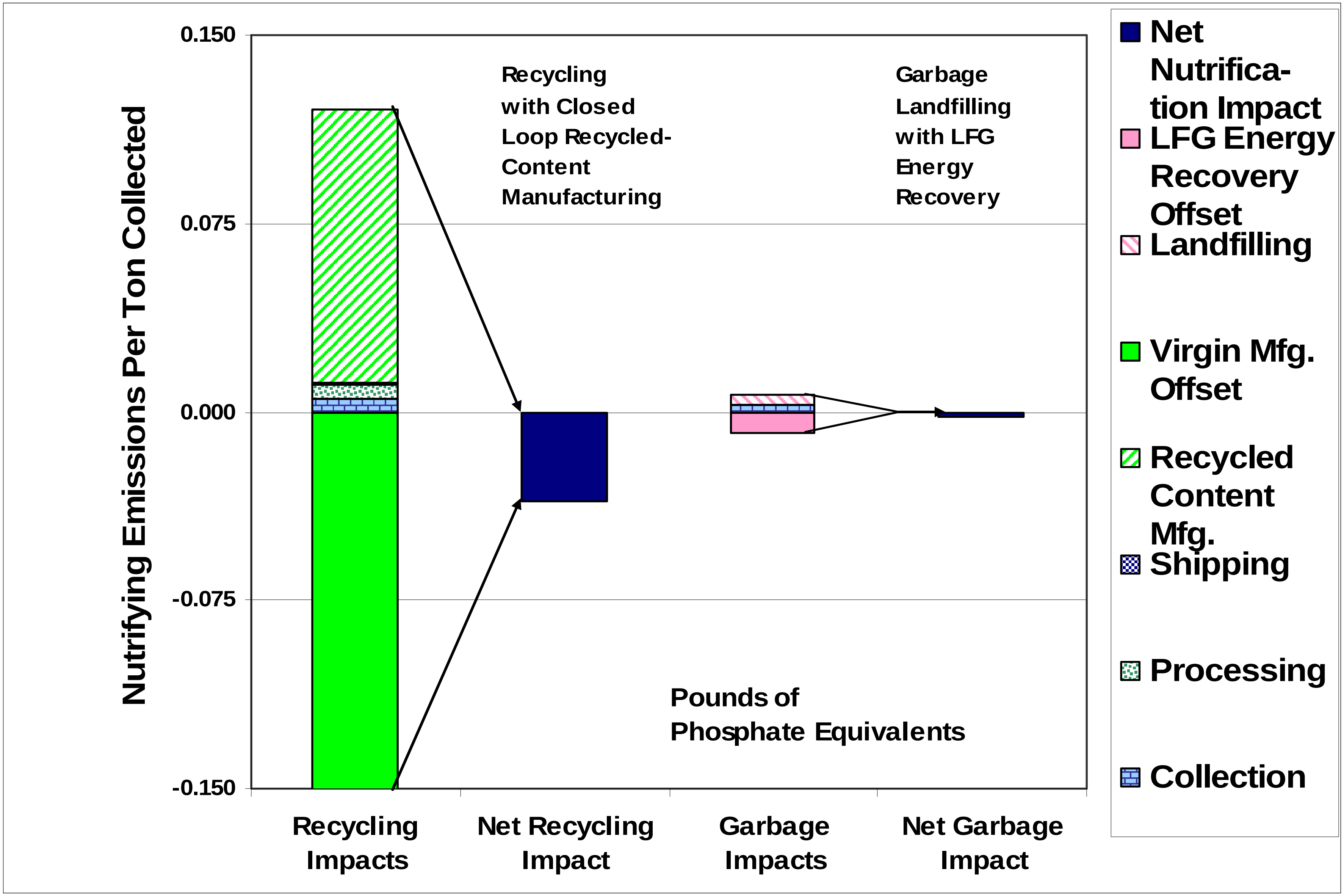


Figure A-5

Comparative Eutrophication Potential Emissions for SLO Recycling vs. Landfilling



D. Potential Human Health Impacts from Recycling Compared with Landfilling

The BEES environmental impact assessment methodology provides two indices for measuring threats to human health. We used both of them to assess the public health burdens imposed by emissions of substances inventoried in the DST and its associated Database. These are (1) estimated disability-adjusted life year (DALY) losses caused by emissions of criteria air pollutants (nitrogen oxides, particulates, and sulfur oxides), and (2) an index denominated in grams of toluene equivalents for potential human health effects from emissions of toxic substances. DALYs '...account for years of life lost and years lived with disability, adjusted for the severity of the associated unfavorable health conditions.'[10]

The DST provides emissions data for all three substances included in the DALY index, but only tracks emissions for sixteen of the more than two hundred toxic substances included in the BEES human health impact index for toxics. Nevertheless, the sixteen toxics that are tracked by the DST provide enough of an indication of the relative potential for human health impacts from toxic releases due to recycling and landfilling that their assessment via the BEES human toxicity index is reported here.

Figure A-6, Comparative DALY Losses for SLO Recycling vs. Landfilling, shows the estimated losses of microDALYs in 2002 caused by criteria air pollutants emitted from collecting recyclables and refuse, and delivering those respective quantities to processing and landfill facilities. Figure A-6 also shows estimated microDALY losses during 2002 from operating the landfill, processing and shipping recyclables to end-use markets, and manufacturing processed recyclables into new products. These impacts on human health caused by air pollution are shown as positive portions of the respective stacked bars for Recycling Impacts and Garbage Impacts in Figure A-6. The offsets from avoidance of virgin-content manufacturing for recycling and avoidance of energy generation at coal-fired power plants for landfilling are shown as negative portions of the respective stacked bars to indicate their potential benefit in reducing DALY losses.

As indicated in Figure A-6 the virgin manufacturing offset (avoidance) benefits of recycling more than compensate for the microDALY losses caused by collecting, processing, and transporting recycled materials to end users, and by the processes employed by end users to manufacture new products from these recycled materials. In addition, the net reduction in microDALY losses per ton of materials collected for recycling during 2002 in SLO County is more than ten times (an order of magnitude) larger than the net reduction in microDALY losses per ton of waste materials collected for landfilling.

Figure A-7, Comparative Potential Human Toxicity Impacts for SLO Recycling vs. Landfilling, shows the potential for human toxicity impacts resulting from emissions of toxic substances during solid waste collection and handling operations. As with other environmental impacts from recycling operations, the potential for human toxic impacts is actually reduced by recycling because of the upstream offsets that accrue as a result of avoiding the manufacture of new products using virgin raw materials. This is shown in Figure A-7 by the bright green negative portion of the stacked bar for Recycling Impacts, indicating that recycling provides an environmental benefit by reducing emissions of toxic pollutants.

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[10] (Lippiatt 2002), page 18.

Figure A-6

Comparative DALY Losses for SLO Recycling vs. Landfilling

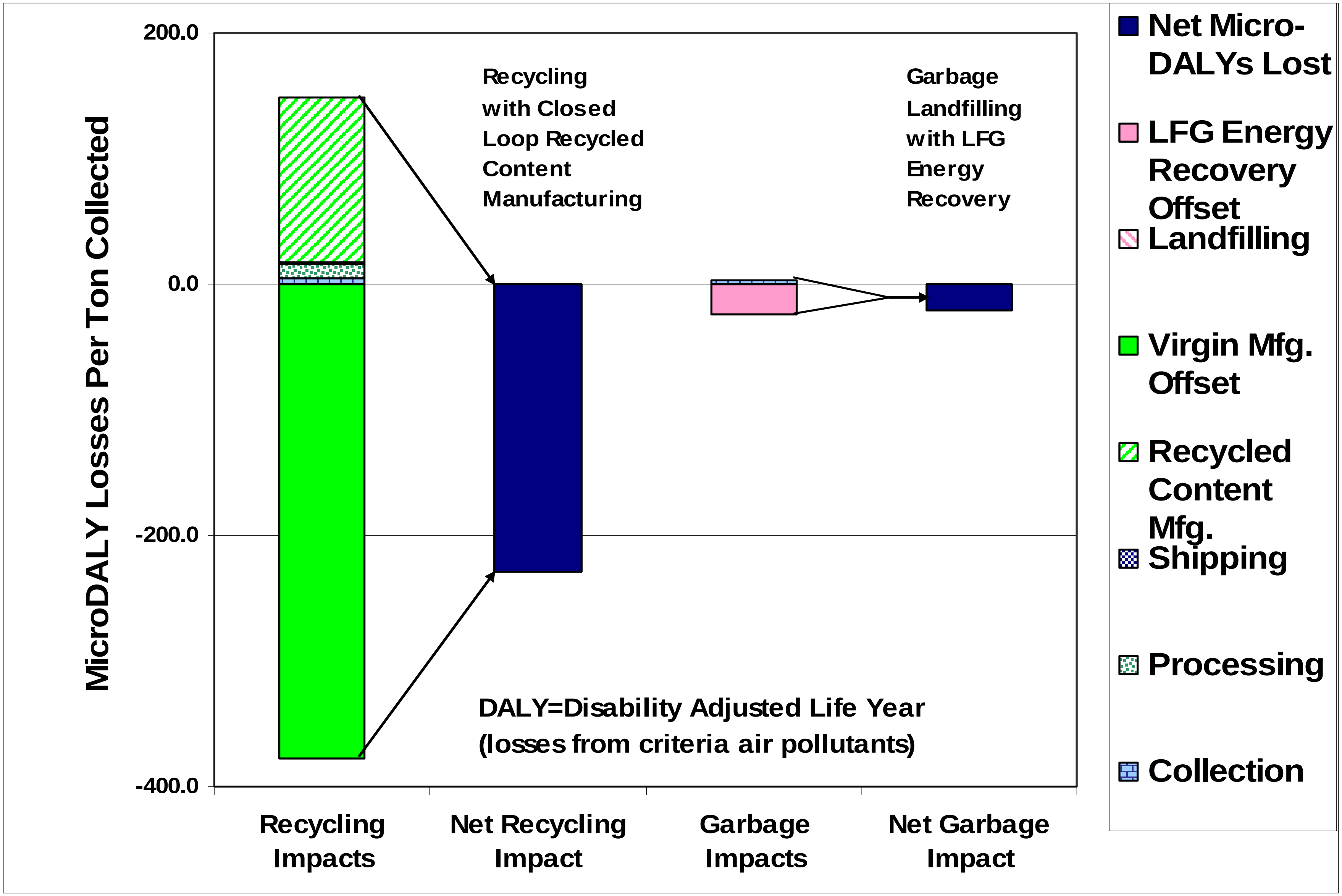
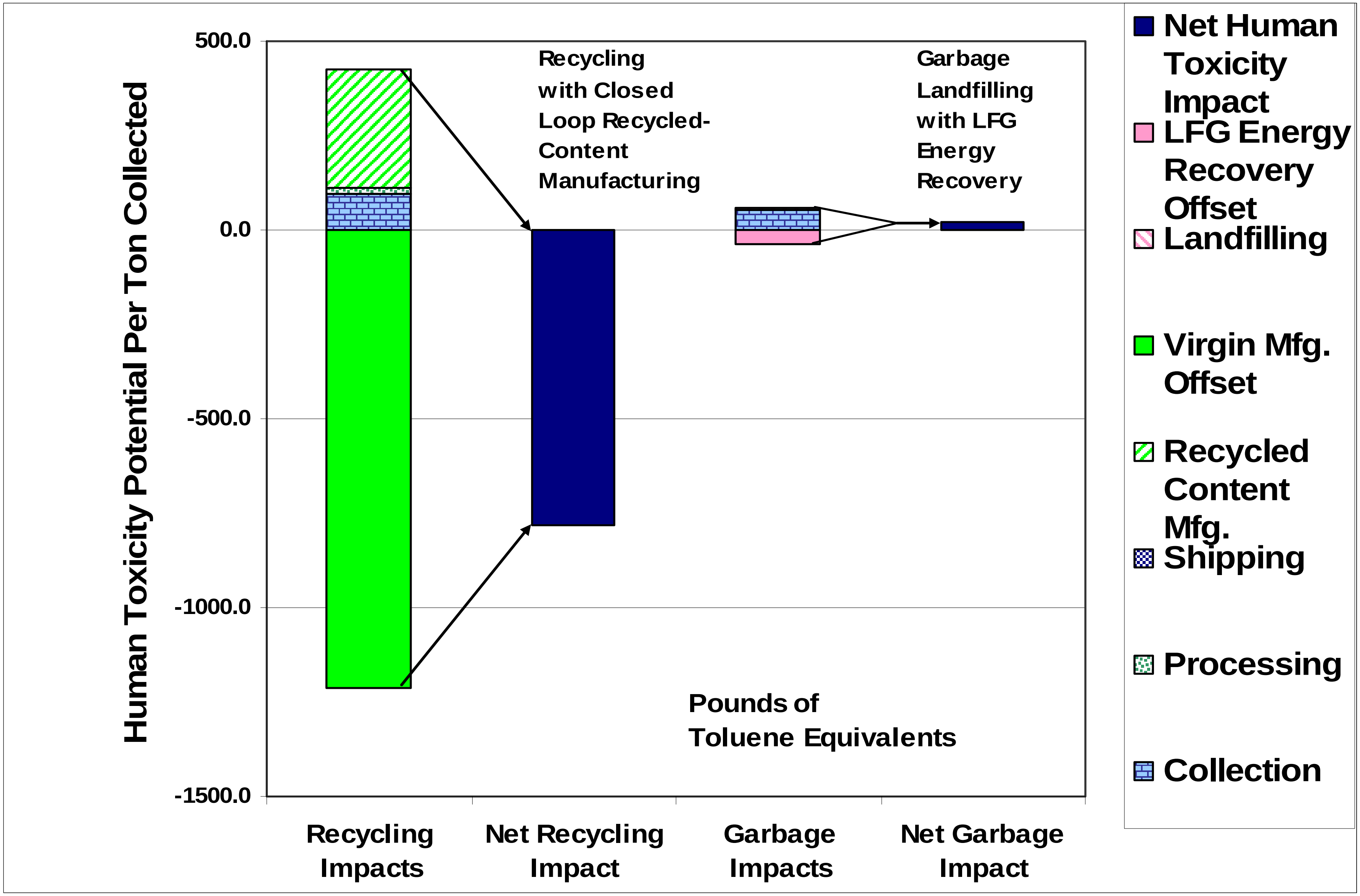


Figure A-7

Comparative Potential Human Toxicity Impacts for SLO Recycling vs. Landfilling



However, for the refuse collection and landfilling method of waste management there is a difference for human toxicity impacts compared with previously discussed impacts. That is, for emissions of compounds that are potentially toxic to humans the emissions offsets from landfill gas recovery and use for generating energy do not outweigh the environmental burdens caused by refuse collection and landfilling operations.

E. Potential Ecological Impacts from Recycling Compared with Landfilling

The final impact measure evaluated by SRMG in the SLO IWMA study was for ecotoxicity. The BEES '...ecological toxicity impact measures the potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems……characterization factors for potential ecological toxicity use 2,4-dichlorophenoxy-ecetic acid (2,4-D) as the reference substance.'[11] There are more than 150 substances in the BEES ecological toxicity assessment, but the DST and Database measure emissions for only fourteen of these. Nevertheless, as with the human toxicity potential measure discussed above, comparing ecotoxicity index scores for recycling and landfilling on the basis of those substances that are included in the DST still provides another important piece of information to use in evaluating the relative environmental burdens that may be imposed when managing solid wastes using these two methods.

Figure A-8, Comparative Potential Ecological Toxicity Impacts for SLO Recycling vs. Landfilling, shows the ecotoxicity index values from emissions of these fourteen substances according to the BEES measure for assessing the potential for ecological toxicity from releases during collection and handling of solid waste materials. As was the case for every measure of environmental burden calculated in the SLO IWMA study, ecotoxicity potential is reduced by recycling. As with the other environmental burdens the reason that recycling reduces ecological toxicity potential is that avoided production of goods from virgin materials reduces pollutant emissions more than the combined amount of releases from collection, processing, transporting, and manufacturing recycled materials into new products.

There is a new factor in this impact assessment, however, for refuse collection and landfilling. That is that recovery of energy from landfill gas actually increases ecotoxicity potential whereas it reduced environmental burdens for the other impact measures. What is not new is that recycling once again dominates landfilling with energy recovery due to the substantial ecologically toxic pollutant releases that are avoided when products are made with recycled rather than virgin materials.

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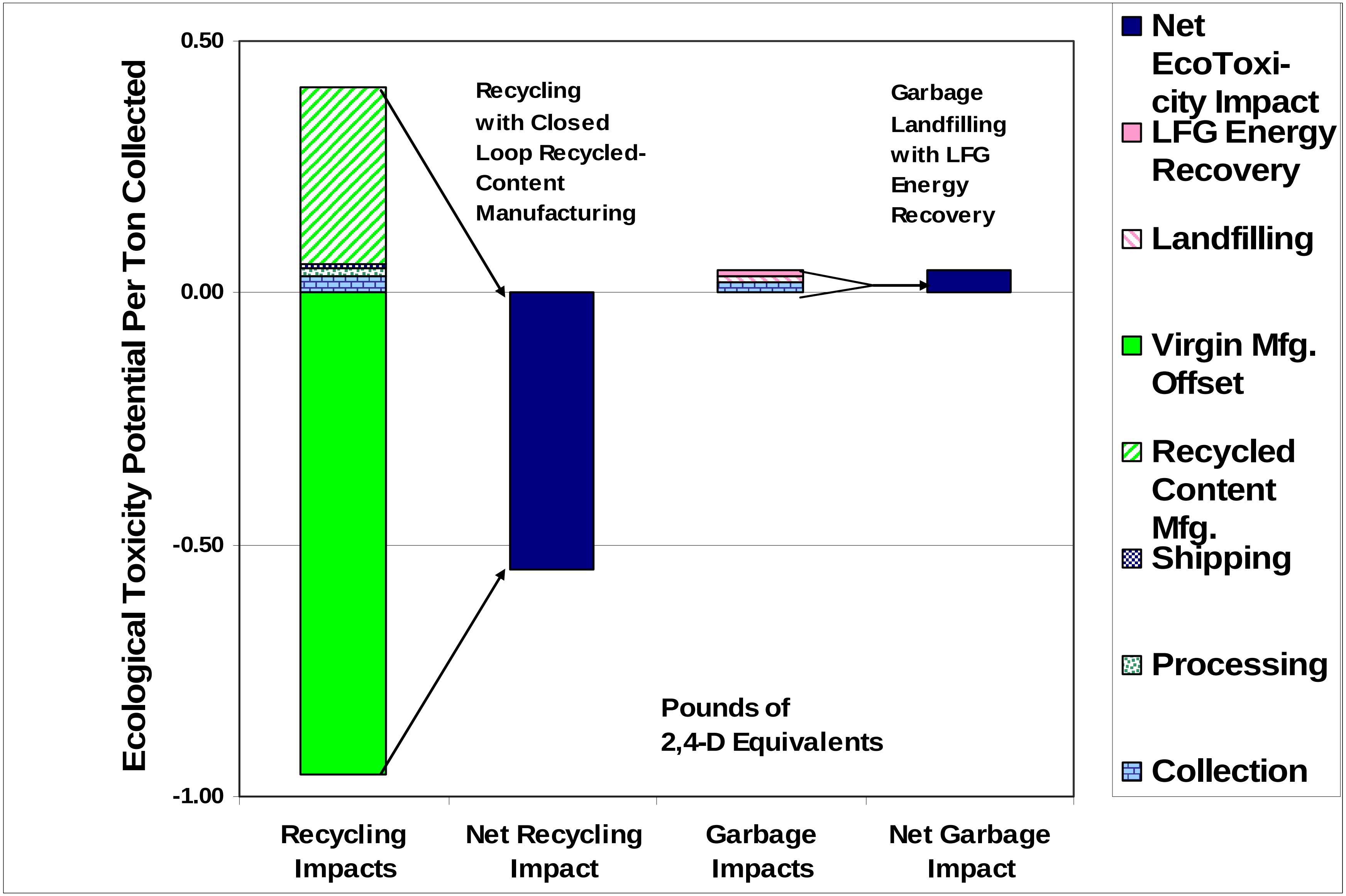
[11] (Lippiatt 2002), page 22.

Figure A-8

Comparative Potential Ecological Toxicity Impacts for SLO Recycling vs. Landfilling



V. Appendix B – Detail on Results for Recycling Vs. WTE Incineration

A. Energy Savings from Recycling Compared with Incineration

Figure B-1, Comparative Energy Usage for Recycling vs. WTE Incineration, shows estimated energy used in 2002 for collecting recyclables and refuse, and delivering those respective quantities to the recyclables processing facility and to a hypothetical waste-to-energy (WTE) incineration facility located at the Cold Canyon landfill site. Figure B-1 also shows estimated energy for operating the WTE facility, processing and shipping recyclables to end-use markets, and manufacturing processed recyclables into new products. Energy usages for these components of recycling and disposal systems are shown as positive (upward pointing from the zero axis) portions of the respective stacked bars for Recycling Impacts and Garbage Impacts in Figure B-1.

The energy conserved from recycling, as a result of avoiding the manufacture of new products from virgin raw materials, is shown as the bright green negative (downward pointing from the zero axis) portion of the stacked bar for Recycling Impacts. Producing products such as newsprint, cardboard, glass containers, aluminum can sheet and plastic pellets with virgin materials requires 23.3 million Btus, compared with the 10.4 million Btus, or 45% as much energy, needed to make this same quantity and mix of products with the recycled material components that were, on average, in each ton of materials collected for recycling from SLO County households and businesses during 2002.

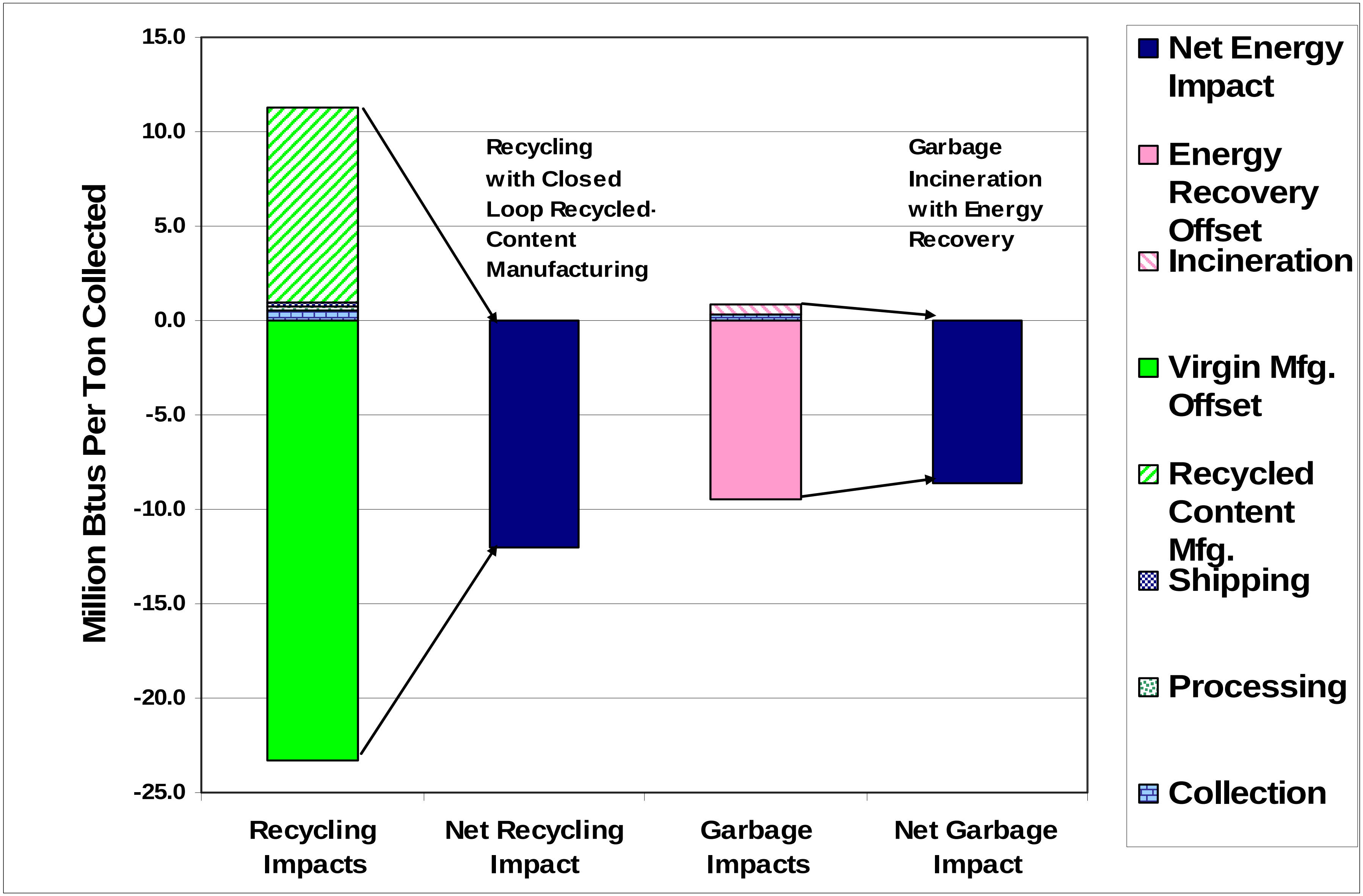
As detailed in Appendix A, given the mix of paper, plastic, metal and glass materials recycled in SLO County, energy savings for individual recycled-content products yield the estimate that producing products with SLO's recycled materials uses only 45% as much energy as would be required to produce that same mix of products with virgin feedstock. Thus, as shown by the dark blue Net Recycling Impact bar in Figure B-1, recycling saves 12 million Btus per ton recycled. As also shown in Figure A-1, these upstream energy savings from recycling are an order of magnitude larger than the estimated 0.9 million Btus needed to collect, process and ship to market the recyclables collected in SLO County's curbside/on-site recycling programs.

Estimated energy captured from collected refuse incinerated at a hypothetical WTE facility is also shown in Figure B-1 as a negative offset to the estimated energy required to collect and incinerate refuse. As indicated in Figure B-1, the energy offset from WTE, estimated at 9.5 million Btus per ton of collected refuse, is greater than the estimated total energy of 0.8 million Btus required for collecting and incinerating refuse.

As indicated in Figure B-1, recycling in SLO County is 40% more effective at reducing global energy demand than the hypothetical WTE incineration facility. Thus, one would need to look at cost-effectiveness of recycling versus WTE incineration, recyclability of the materials remaining in refuse, or some other criterion besides energy efficiency to find a reason for not maximizing separation of recyclable materials from refuse so that they can be recovered for use in manufacturing recycled-content products.

Figure B-1

Comparative Energy Usage for SLO Recycling vs. WTE Incineration



B. Greenhouse Gas Reductions from Recycling Compared with Incineration

Figure B-2, Comparative Greenhouse Gas Emissions for SLO Recycling vs. WTE Incineration, shows estimated emissions of greenhouse gases in 2002 from collecting recyclables and refuse, and delivering those respective quantities to processing and landfill facilities. Figure B-2 also shows estimated greenhouse gas emissions from operating a hypothetical WTE facility, processing and shipping recyclables to end-use markets, and manufacturing processed recyclables into new products. Greenhouse gas emissions for these components of recycling and disposal systems are shown as positive portions of the respective stacked bars for Recycling Impacts and Garbage Impacts in Figure B-2.

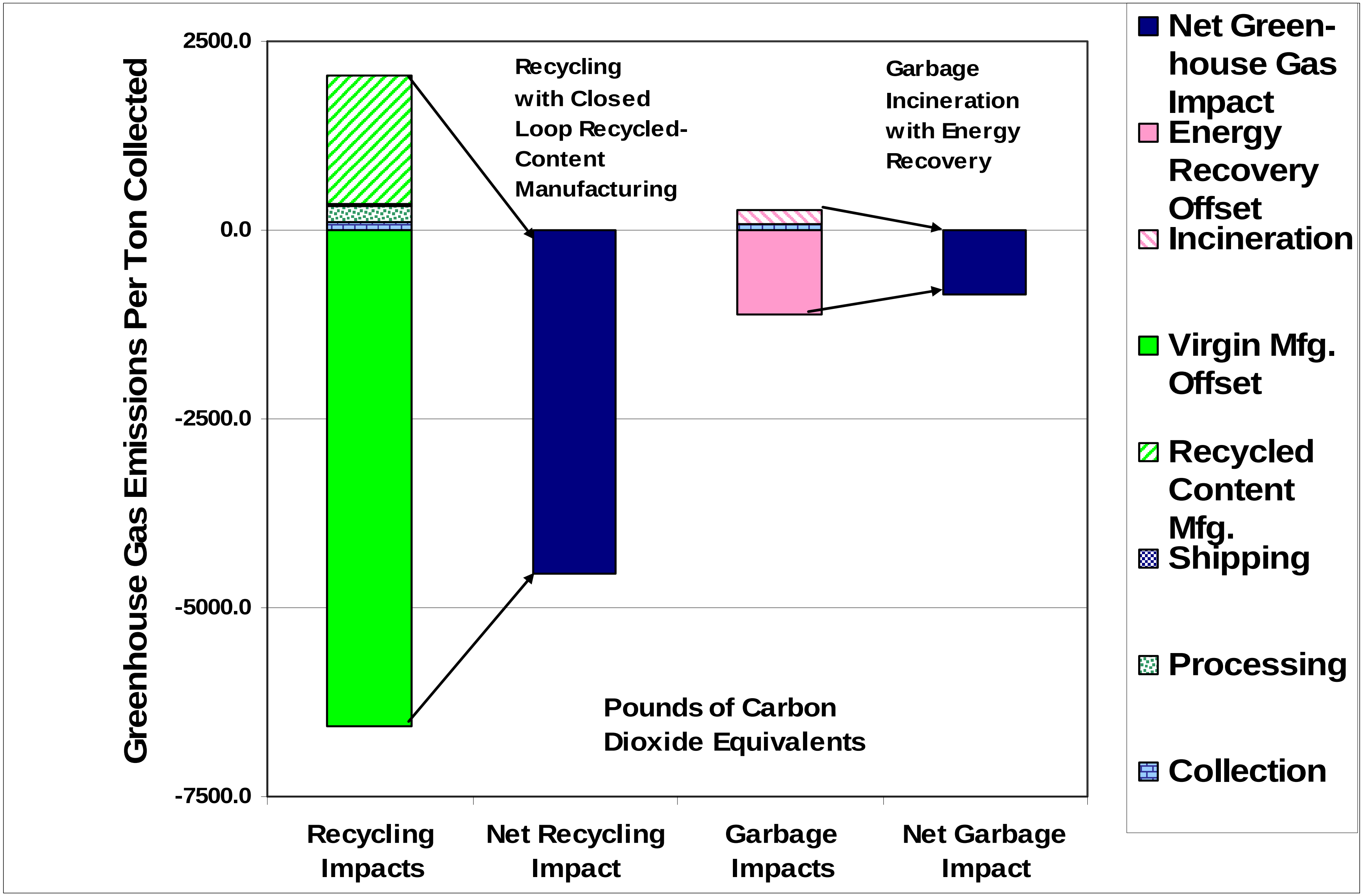
Greenhouse gas emission offsets from recycling, as a result of avoiding the manufacture of new products from virgin raw materials, are shown as the bright green negative portion of the stacked bar for Recycling Impacts. Producing products such as newsprint, cardboard, glass containers, aluminum can sheet and plastic pellets with virgin materials emits 6,577 pounds of carbon dioxide equivalents, compared with the 1,685 pounds emitted to manufacture this same quantity and mix of products with the recycled materials components that were, on average, in each ton of materials collected for recycling from SLO households and businesses during 2002. That is, using materials recycled in SLO County during 2002 to manufacture new products reduced greenhouse gas emissions to a level that is just 26% of the quantity of carbon dioxide equivalents that would have been emitted to make this same quantity and mix of new products from virgin raw materials.

Estimated greenhouse gas offsets for energy generated from WTE incineration are shown as the bright pink negative portion of the Garbage Impacts stacked bar. These reductions in greenhouse gases that would otherwise have been generated at coal fired power plants to produce the energy generated by a hypothetical WTE facility are substantial enough to more than offset the greenhouse effect of emissions from the WTE facility itself and from diesel fuels consumed in collecting refuse and hauling it to the WTE site.

The Net Garbage Impact bar in Figure B-2 indicates that WTE incineration of collected refuse reduces global greenhouse gas emissions by 857.5 pounds of carbon dioxide equivalents per ton of collected refuse. Recycling, on the other hand, reduces greenhouse gas emissions by 4,537.3 pounds for each ton of collected recyclables according to the Net Recycling Impact bar shown in Figure B-2. On this basis recycling is 5.3 times more effective per ton of material handled than WTE incineration in terms of reducing global greenhouse gas emissions. Furthermore, the greenhouse gas impacts from collecting, processing and shipping recycled materials to market are more than an order of magnitude smaller than the upstream prevention of emissions achieved by using recycled rather than virgin materials to manufacture new products.

Figure B-2

Comparative Greenhouse Gas Emissions for SLO Recycling vs. WTE Incineration



C. Acidification and Eutrophication Potential Reductions from Recycling Compared with Incineration

As Figure B-2 did for greenhouse gases, Figures B-3, Comparative Acidification Potential Emissions for SLO Recycling vs. WTE Incineration, and B-4, Comparative Eutrophication Potential Emissions for SLO Recycling vs. WTE Incineration, show the same advantages over WTE Incineration for collecting recyclables, processing them, and shipping them to end users where they are used instead of virgin materials in manufacturing new products. As indicated in Figures B-3 and B-4, recycling is 23% more effective than WTE Incineration at reducing emissions of acidifying substances that cause such environmental burdens as acid rain, and 44% more effective at reducing emissions of eutrophying substances that cause environmental damages such as nutrification of lakes and streams. Also, the environmental burdens for these two impact categories imposed by collection, processing and shipping recycled materials to end users are again quite small compared with the environmental burdens avoided when recycled materials replace virgin raw materials as input feedstock for manufacturing new products.

Figure B-3

Comparative Acidification Potential Emissions for SLO Recycling vs. WTE Incineration

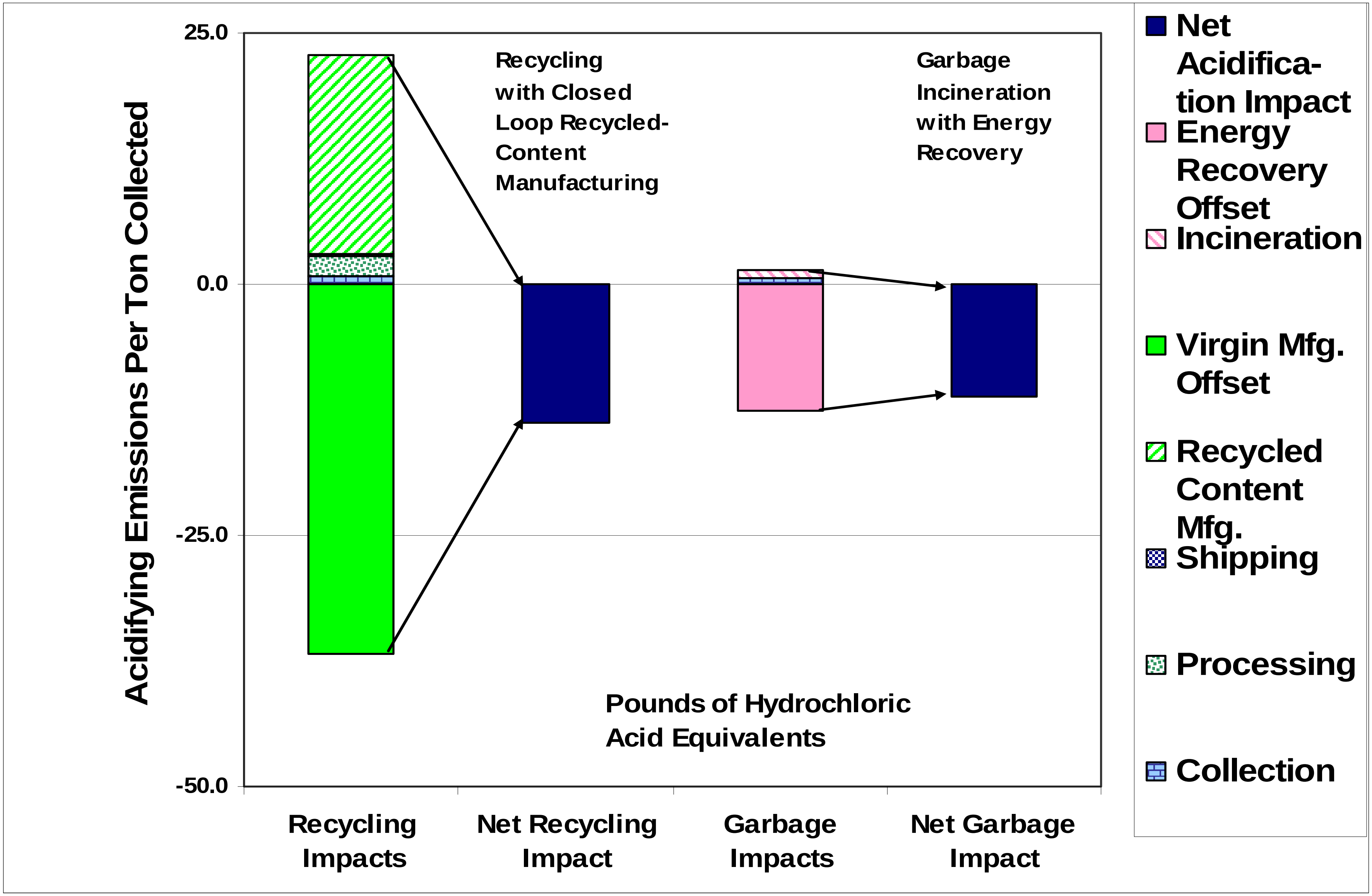
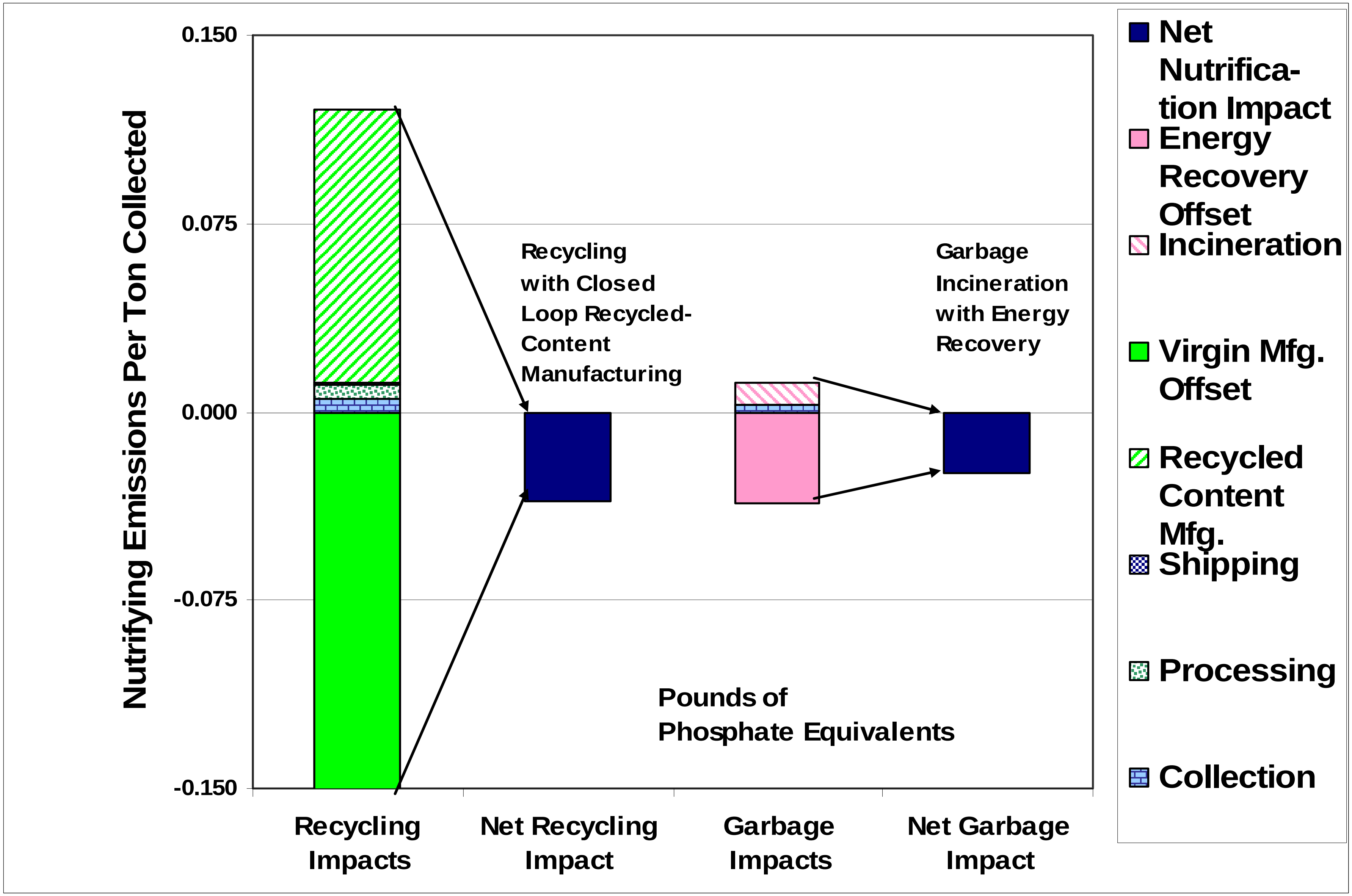


Figure B-4

Comparative Eutrophication Potential Emissions for SLO Recycling vs. WTE Incineration



D. Potential Human Health Impacts from Recycling Compared with Incineration

Appendix A discussed the BEES environmental impact assessment methodology for the two indices reported herein for measuring threats to human health. Figure B-5, Comparative DALY Losses for SLO Recycling vs. WTE Incineration, shows estimated losses of microDALYs caused by criteria air pollutants emitted from collecting recyclables and refuse, and delivering those respective quantities to processing and WTE facilities. Figure B-5 also shows estimated microDALY losses from operating the WTE incinerator, processing and shipping recyclables to end-use markets, and manufacturing processed recyclables into new products. These impacts on human health caused by air pollution are shown as positive portions of the respective stacked bars for Recycling Impacts and Garbage Impacts in Figure B-5. The offsets from avoidance of virgin-content manufacturing for recycling and avoidance of energy generation at coal-fired power plants for WTE incineration are shown as negative portions of the respective stacked bars to indicate their potential benefit in reducing DALY losses.

As indicated in Figure B-5 the virgin manufacturing offset (avoidance) benefits of recycling more than compensate for the microDALY losses caused by collecting, processing, and transporting recycled materials to end users, and by the processes employed by end users to manufacture new products from these recycled materials. In addition, the net reduction in microDALY losses per ton of materials collected for recycling is 2.75 larger than the net reduction in microDALY losses per ton of waste materials collected for WTE incineration.

Figure B-6, Comparative Potential Human Toxicity Impacts for SLO Recycling vs. WTE Incineration, shows the potential for human toxicity impacts resulting from emissions of toxic substances during solid waste collection and handling operations. As with other environmental impacts from recycling operations, the potential for human toxic impacts is actually reduced by recycling because of the upstream offsets that accrue by avoiding the manufacture of new products using virgin raw material feedstock. This is shown in Figure B-6 by the bright green negative portion of the stacked bar for Recycling Impacts, indicating that recycling provides an environmental benefit by reducing emissions of toxic pollutants.

However, for the refuse collection and WTE incineration method of waste management there is a difference for human toxicity impacts compared with previously discussed impacts for WTE Incineration. That is, for emissions of compounds that are potentially toxic to humans the emissions offsets from energy recovery at a WTE facility do not outweigh the environmental burdens caused by refuse collection and WTE facility operations. This result is noteworthy because Figure B-6 does not take into account air emissions of mercury and dioxins, two pollutants whose emissions often are of concern at WTE facilities.

Figure B-5

Comparative DALY Losses for SLO Recycling vs. WTE Incineration

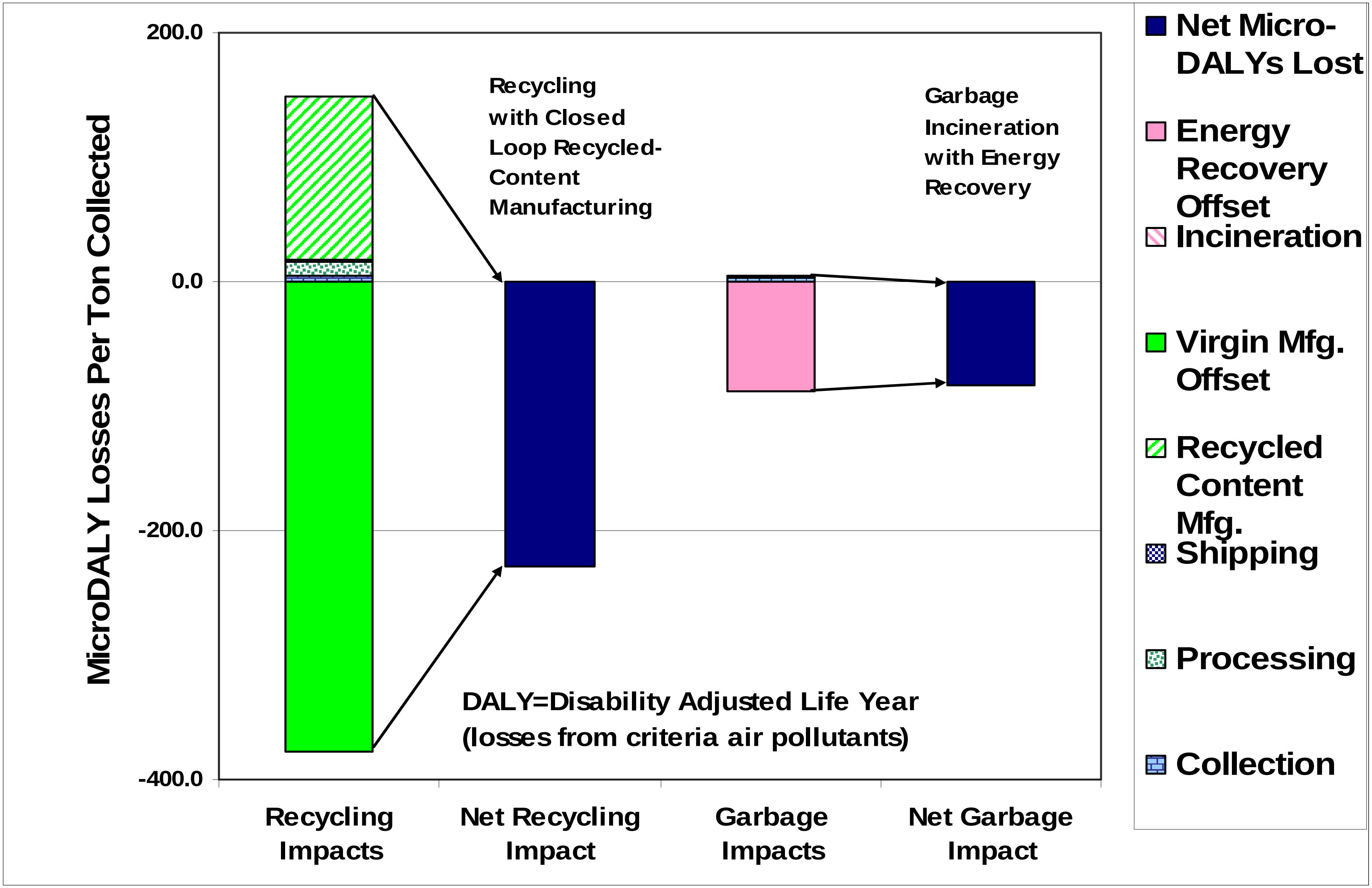
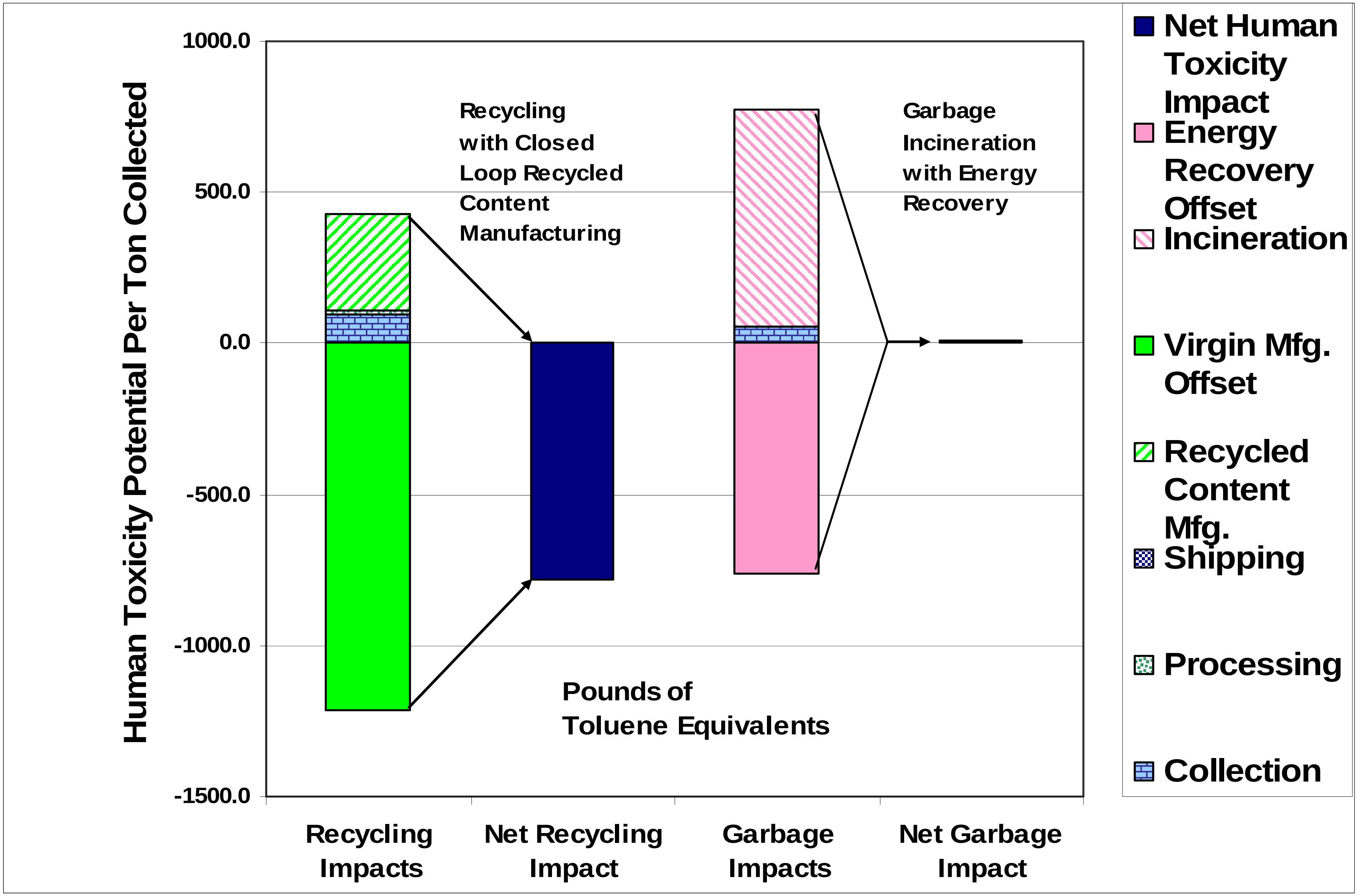


Figure B-6

Comparative Potential Human Toxicity Impacts for SLO Recycling vs. WTE Incineration

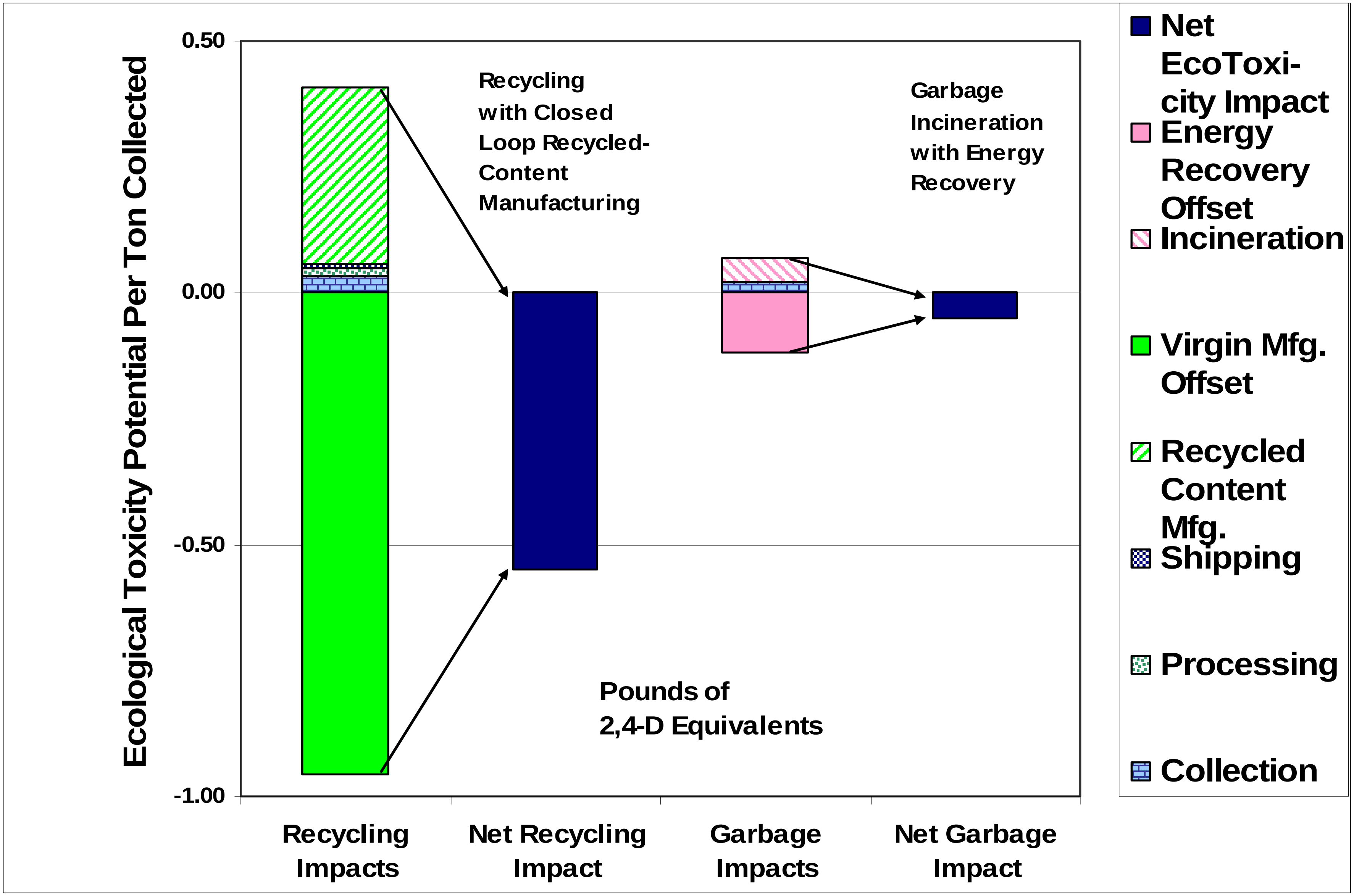


E. Potential Ecological Impacts from Recycling Compared with Incineration

As for recycling versus landfilling, the final impact measure evaluated by SRMG for recycling versus incineration was for ecotoxicity. Figure B-7, Comparative Potential Ecological Toxicity Impacts for SLO Recycling vs. WTE Incineration, shows potential ecotoxicity from emissions associated with recycling and WTE incineration. As was the case for human toxicity measures, ecotoxicity potential is reduced by recycling. As before the reason is that avoided production of goods from virgin materials reduces pollutant emissions more than the combined amount of releases from collection, processing, transporting, and manufacturing recycled materials into new products. Furthermore, the net reduction in ecotoxicity potential from recycling is eleven times greater than the net reduction from WTE incineration, as shown in Figure B-7.

Figure B-7

Comparative Potential Ecological Toxicity Impacts for SLO Recycling vs. WTE Incineration



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