United States
Environmental Protection
Agency

Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response

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Legal Note

This document contains information designed to be useful and helpful to governments, the public, and the regulated community. This document does not impose legally binding requirements, nor does it confer legal rights, impose legal obligations, or implement any statutory or regulatory provisions. This document does not restrict, expand or otherwise change EPA's authority to address greenhouse gas emissions under existing statutes. This document does not change or substitute for any statutory or regulatory provisions. This document presents technical information based on EPA's current understanding of the link between global climate change and materials and land use management programs. Finally, this is a living document and may be revised periodically without public notice.

The EPA welcomes public comments on this document at any time and will consider those comments in any future revisions of this document.

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Appendix A

Executive Summary

The Intergovernmental Panel on Climate Change has determined that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."[1] The U.S. Environmental Protection Agency (EPA) has proposed that climate change is primarily the result of greenhouse gas (GHG) emissions, its effects will worsen over time in the absence of regulatory action, and the overall rate and magnitude of human-induced climate change will likely increase, such that risks to public health and welfare will likewise grow over time so that future generations will be especially vulnerable; their vulnerability will include potentially catastrophic harms.[2]

To respond to the risk associated with climate change, this document describes the link between climate change and the materials and land management programs carried out by EPA's Office of Solid Waste and Emergency Response (OSWER), and its federal, regional, state, tribal, community, and other public and private partners. The purpose of this document is two-fold. First, in order to increase understanding of the link between materials and land management and GHG emissions, this document presents an estimate of the portion of U.S. GHG emissions associated with materials and land management practices. Second, it presents a set of materials and land management scenarios—referred to as total technical potential scenarios—as a first step to identifying areas of opportunity for EPA and its partners to reduce GHG emissions through materials and land management.

Introduction

OSWER and its partners implement environmental programs that are broadly categorized into three areas: materials management through resource conservation and recovery; land management through prevention of contaminant releases and cleanup and reuse of contaminated sites; and emergency response and preparedness. These three program areas all have direct impacts on communities across the United States. *Materials management* refers to how we manage material resources as they flow through the economy, from extraction or harvest of materials and food (e.g., mining, forestry, and agriculture), production and transport of goods, provision of services, reuse of materials, and, if necessary, disposal. EPA promotes materials management approaches that serve human needs by using and reusing resources productively and sustainably throughout their life cycles, minimizing both the amount of materials involved and the associated environmental impacts. *Land management* refers to how we manage and use land to provide open space and habitat, food, natural resources, and places for people to live, work, and recreate. EPA promotes integrated land management strategies that use land as productively and sustainably as possible by preventing and minimizing the occurrence of contamination and cleaning up, reusing, and restoring contaminated land for beneficial reuse. EPA's *emergency response and preparedness* programs will have a key role in adapting to the environmental changes spurred by climate change.

How we manage our materials and land—two of OSWER's three core program areas—has a significant impact on U.S. GHG emissions and sinks. Strategies for reducing emissions through materials and land management also have substantial environmental and economic co-benefits for communities.

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[1] Intergovernmental Panel on Climate Change. *Fourth Assessment Report (AR4).* p. 30. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[2] Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act. Proposed Rule. 74 Fed. Reg. 18886-18910. April 24, 2009.

Additionally, unlike many GHG mitigation options, materials and land management are heavily influenced by states and communities. Working with its partners, EPA can leverage its materials and land management programs to achieve measurable GHG reductions while yielding multiple environmental, human health, and economic benefits for communities and the nation. This document promotes the recognition that materials and land management programs, while complementing other EPA program goals, can also produce significant climate change mitigation benefits.

Understanding U.S. GHG Emissions

The United States annually reports its GHG emissions in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* ("the Inventory").[3] This report quantifies the country's primary anthropogenic sources and sinks of GHG emissions based on comprehensive and detailed methodologies consistent with international guidance that enables parties to the United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different emission sources and GHGs to climate change. The information in the Inventory is often summarized by apportioning emissions to economic sectors. This sector-based view of data in the Inventory is important for framing a range of GHG emissions mitigation strategies, including end-of-pipe strategies for reducing emissions and technology substitutions within a sector.

To better understand and describe the connections between materials and land management and climate change, this report presents a systems-based view of U.S. GHG emissions, where each system represents and comprises all the parts of the economy working to fulfill a particular need. For example, the provision of food system includes all emissions from the electric power, transportation, industrial, and agricultural sectors associated with growing, processing, transporting, and disposing of food. The systems view is helpful for framing opportunities to reduce GHG emissions through prevention-oriented mitigation strategies that act across an entire system. The systems are selected to illustrate the GHG emissions associated with materials and land management, as shown in Figure ES-1. Appendix A provides the methodology used for this analysis, including key assumptions and references for source data.

Combined, materials management is associated with an estimated 42% of total U.S. GHG emissions and land management is associated with an estimated 16% of total U.S. GHG emissions. Based on a preliminary estimate provided in this report, GHG emissions from greenfield development are equivalent to approximately an additional 4% of total U.S. emissions.[4] The land-based carbon sink reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* has been included in this figure to help convey the effect land management has on U.S. emissions and sinks. The land-based carbon sink is equivalent to 13% of 2006 U.S. GHG emissions.[5]

Figure ES-1 shows the relative magnitude of the emissions associated with materials and land management. By allocating the emissions reported in the *Inventory of U.S. Greenhouse Gas Emissions*

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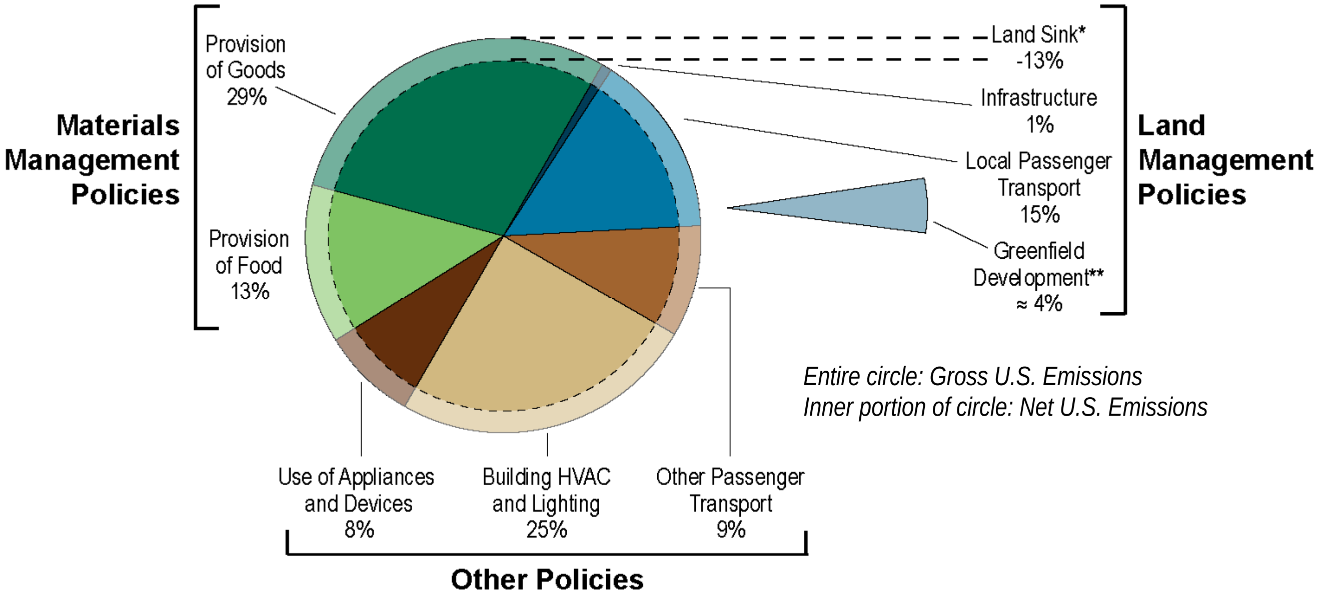
[3] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html. This report relies on the Inventory data published in 2008; a more recent version, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, was published in 2009 and can be found at http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[4] Emissions from greenfield development are not calculated in the U.S. Inventory, but this estimate may overlap with existing land sink value.

[5] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* p. ES-14. Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html

and Sinks by system, the impact of decisions related to materials and land management on the country's total GHG emissions and sinks is evident.

Figure ES-1
Systems-Based View of U.S. GHG Emissions (2006)



This figure presents the U.S. GHG emissions data reported in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, allocated to systems, and by materials and land management, as described in Appendix A. Emissions from U.S. territories are not included in this figure.

* The Land Sink, represented by the outer ring, offset the equivalent of 13% of total U.S. anthropogenic emissions in 2006. It is graphically represented here as a semi-transparent ring that erases a portion of emissions from all other slices shown in the pie chart. The entire pie chart represents total U.S. emissions in 2006; once the offset provided by the Land Sink is applied, the inner portion of the pie chart represents net U.S. emissions.

** Greenfield development represents emissions from land clearing (equivalent to roughly 4% of U.S. emissions in 2006); this calculation is not included in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, and is therefore depicted outside of the pie chart. It may include some overlap with the existing land sink value.

Potential GHG Reductions through Materials and Land Management

Significant GHG emission reductions have been achieved to date in the United States by EPA, states, local governments, and stakeholders through numerous materials and land management-related activities.[6] Selected examples include:

- In 2006, U.S. municipal solid waste (MSW) recycling resulted in the avoidance of nearly 183 million metric tons of carbon dioxide equivalent ($MMTCO_2E$) in GHG emissions.[7]
- In 2006, waste-to-energy recovery systems combusted MSW and resulted in the avoidance of 17 $MMTCO_2E$ in GHG emissions.[8]
- In 2005, EPA's WasteWise partners reported source reduction and recycling activities that resulted in the avoidance of 27 $MMTCO_2E$ in GHG emissions.[9]

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[6] The following tools were used to calculate the selected examples of GHG emissions reductions, in addition to the data sources referenced for each example below: U.S. EPA. March 2009. *Greenhouse Gas Equivalencies Calculator*; U.S. EPA. September 2008. *WAste Reduction Model (WARM)*; and Fogt, Robert. 2008. *Online Conversion Tool for Energy*.

[7] U.S. EPA, Office of Solid Waste and Emergency Response. November 2007. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006*, p. 1-8.

[8] Ibid.

[9] U.S. EPA. October 2006. *WasteWise 2006 Annual Report*. p. 1. Available at: http://www.epa.gov/waste/partnerships/wastewise/pubs/report06.pdf

To help illustrate the potential for GHG reduction and avoidance opportunities from materials and land management practices, this analysis includes several “total technical potential” scenarios. Box ES-1 summarizes these scenarios and Appendix A describes the analytical methodology, assumptions, and data sources used to calculate the potential impacts for these hypothetical changes in materials and land management practices.

The term *total technical potential* refers to the estimated GHG emission reduction that could occur if the scenarios presented are achieved, setting aside economic, institutional, or technological limitations. Such scenarios, which are a common first step in climate policy analysis, allow for the examination of the GHG reduction potential of various mitigation strategies contained in those scenarios. These total technical potential scenarios are useful for scoping the order-of-magnitude impact of an activity and identifying areas of promise for more detailed analysis and potential activity. They also illustrate how changes in behavior can lead directly to significant reductions of GHG emissions on a national scale.

The total technical potential scenarios presented here represent early analysis based on existing and available data. As more analysis is completed, total technical potential scenarios can be generated for a greater number of materials and land management approaches.

Box ES-1: Summary of Total Technical Potential Scenarios

Source Reduction		Estimated GHG Emission Benefit*
Reduce packaging use by:	50%	40—105 MMTCO$_2$E/yr
	25%	20—50 MMTCO$_2$E/yr
Reduce use of non-packaging paper products by:[10]	50%	20—70 MMTCO$_2$E/yr
	25%	10—35 MMTCO$_2$E/yr
Extend the life of personal computers by:	50%	25 MMTCO$_2$E/yr
	25%	15 MMTCO$_2$E/yr
Reuse/Recycling		
Increase recycling of construction and demolition debris to:	100%	150 MMTCO$_2$E/yr
	50%	75 MMTCO$_2$E/yr
	25%	40 MMTCO$_2$E/yr
Increase national municipal solid waste (MSW) recycling and composting rate from 2006 rate (32.5%) to:	100%	300 MMTCO$_2$E/yr
	50%	70—80 MMTCO$_2$E/yr
Increase composting of food scraps from 2006 rate (2%) to:	100%	20 MMTCO$_2$E/yr
	50%	10 MMTCO$_2$E/yr
	25%	5 MMTCO$_2$E/yr
Energy Recovery / Disposal		
Combust percentage of currently landfilled MSW:	100%	70—120 MMTCO$_2$E/yr
	50%	35—60 MMTCO$_2$E/yr
	25%	20—30 MMTCO$_2$E/yr
Combust MSW remaining if national recycling rate is increased to 50%:		65—110 MMTCO$_2$E/yr
Capture percentage of currently emitted methane at U.S. landfills for electricity generation:	100%	150 MMTCO$_2$E/yr
	50%	70 MMTCO$_2$E/yr
	25%	35 MMTCO$_2$E/yr

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[10] Non-packaging paper products include magazines and third class mail, newspaper, office paper, phonebooks, and textbooks.

Box ES-1: Summary of Total Technical Potential Scenarios

Land Revitalization		Estimated GHG Emission Benefit*
Shift 60% of expected new development to compact development patterns:[11]		79 MMTCO$_2$E/yr
Reuse percentage of qualifying EPA-tracked contaminated land for utility-scale solar:[12]	100%	2,200 MMTCO$_2$E/yr
	50%	1,100 MMTCO$_2$E/yr
	25%	540 MMTCO$_2$E/yr
Reuse percentage of qualifying EPA-tracked contaminated land for community and utility-scale wind:[13]	100%	40 MMTCO$_2$E/yr
	50%	20 MMTCO$_2$E/yr
	25%	10 MMTCO$_2$E/yr
Reduce electricity use for the most energy-intensive treatment technologies at National Priorities List sites by:	100%	0.4 MMTCO$_2$E/yr
	50%	0.2 MMTCO$_2$E/yr
	25%	0.1 MMTCO$_2$E/yr
Reforest percentage of qualifying former mine lands for carbon sequestration:	100%	4 MMTCO$_2$E/yr
	50%	2 MMTCO$_2$E/yr
	25%	1 MMTCO$_2$E/yr

* Most of the total technical potential scenarios presented in this table have been rounded to one significant figure. See following Appendix A for more detail on these estimates.

Looking Forward

There is a strong link between U.S. GHG emissions and the management of materials and land. EPA, along with its partners, can help address the challenges of global climate change through materials and land management programs. As we develop programs and policies with our partners, more detailed studies that account for both the limitations and opportunities of economic, technical, and policy aspects of the scenarios introduced in this paper will be needed.

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[11] Expected annual benefit through 2030.

[12] The 100% scenario represents 141 times the projected increase in solar power between 2008 and 2030. See Appendix for more detail.

[13] The 100% scenario represents 75% of projected increase in wind power between 2008 and 2030. See Appendix for more detail.

SECTION 1
INTRODUCTION

Climate change is a serious global challenge. Atmospheric greenhouse gas (GHG) concentrations have increased significantly from pre-industrial levels as a result of human activities. Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. [14] Furthermore, the U.S. Environmental Protection Agency (EPA) has proposed that climate change is primarily the result of GHG emissions, its effects will worsen over time in the absence of regulatory action and the overall rate and magnitude of human-induced climate change will likely increase, such that risks to public health and welfare will likewise grow over time so that future generations will be especially vulnerable; their vulnerability will include potentially catastrophic harms.[15]

A growing body of literature discusses potential impacts of climate change and the means to adapt to these changes. It is predicted that "even where regions on the whole may be able to successfully adapt to a limited climate change, specific individuals and communities could still be displaced and harmed by climate change." [16] Of particular concern are those communities that have strong ties and associations with specific areas and resources that are exposed and sensitive to climate change (e.g., through sea-level rise, increased drought, extreme heat), derive a share of their income from climate sensitive activities such as agriculture or fishing, and lack financial and other means to adapt.[17] Arctic communities, for example, are already adapting to climate change, but both internal and external stressors challenge their adaptive capacity.[18]

The U.S. federal government has implemented programs to slow the growth of GHG emissions, strengthen science, technology and institutions, and enhance international cooperation. Since the early 1990s, the federal government has promoted voluntary and incentive-based programs to reduce emissions and established programs to advance climate technology and science. These programs focus on energy efficiency, renewable energy, methane and other non-carbon dioxide gases, agricultural practices, and implementation of technologies to achieve GHG reductions. In April 2009 the EPA Administrator proposed to find that greenhouse gases in the atmosphere may reasonably be anticipated to endanger public health and welfare within the meaning of Section 202(a) of the Clean Air Act. The Administrator further proposed to find that the combined emissions of CO_2, CH_4, N_2O, and HFCs from new motor vehicles and new motor vehicle engines contribute to the atmospheric concentrations of these key greenhouse gases and hence to the threat of climate change.[19] EPA has also proposed to require GHG emissions reporting by large emitters and announced plans to propose

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[14] Intergovernmental Panel on Climate Change. *Fourth Assessment Report (AR4).* pp. 30, 74, 189. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[15] Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act. Proposed Rule. 74 Fed. Reg. 18886-18910. April 24, 2009.

[16] Easterling, William, Hurd, Brian, and Smith, Joel. 2004. Coping with Global Climate Change: The Role of Adaptation in the United States. Pew Center on Global Climate Change.

[17] Ibid.

[18] Intergovernmental Panel on Climate Change. 2007. Summary for Policymakers in *Climate Change 2007: Impacts, Adaptation and Vulnerability.* p. 15. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[19] Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act. Proposed Rule. 74 Fed. Reg. 18886-18910. April 24, 2009.

GHG emissions standards for all new cars and light-duty trucks (model years 2012-2016) sold in the United States.[20]

Through its materials management and land cleanup programs, EPA's Office of Solid Waste and Emergency Response (OSWER) is an important partner in addressing climate change and reducing U.S. GHG emissions and has a community-level perspective on the response to climate change.

OSWER and its regional, state, tribal, community, and other public and private partners implement environmental programs that are authorized by a number of federal statutes with a range of objectives to support communities and protect human health and the environment. These programs can be broadly categorized into three areas:

- Materials management, through resource conservation and recovery, waste prevention, and safe waste disposal;
- Land management through activities that prevent pollutant releases, and encourage cleanup and reuse of contaminated and potentially contaminated sites; and
- Emergency response to, and preparedness for, contaminant releases and other threats to public health.

How we manage our materials and land—two of OSWER's three core areas—has a significant impact on U.S. GHG emissions and sinks.[21] People produce GHG emissions through a wide array of activities and across multiple locations, including the goods and services we consume, the homes in which we live, the buildings where we work, the transportation of ourselves and our goods from place to place, and the materials we discard. Meanwhile, energy consumption, materials use, municipal waste generation, and land development rates have all outpaced population growth over the last several decades in the United States, contributing to the impact of these activities.[22,23,24,25] There are significant opportunities to reduce or avoid GHG emissions by improving our nation's materials and land management practices; these approaches complement and support end-of-pipe controls, sector-based and other mitigation strategies.

Materials management refers to how we manage material resources as they flow through the economy, from extraction or harvest of materials and food (e.g., mining, forestry, and agriculture), production and transport of goods, provision of services, reuse of materials, and, if necessary, disposal. EPA promotes materials management approaches that serve human needs sustainably by minimizing the amount of materials involved and their associated environmental impacts.[26]

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[20] See e.g., Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act. Proposed Rule. 74 Fed. Reg. 18886-18910 (April 24, 2009). Notice of Upcoming Joint Rulemaking to Establish Vehicle GHG Emissions Standards and CAFE Standards, 74 Fed. Reg. 24007 (May 22, 2009).

[21] Emergency response and preparedness will be a central part of the response to climate change, but is not the focus of this document.

[22] U.S. Department of Energy, Energy Information Administration. *Energy Consumption, Expenditures, and Emissions Indicators, 1949-2007*. Table 1.5 Available at: http://www.eia.doe.gov/emeu/aer/txt/ptb0105.html

[23] University of Michigan, Center for Sustainable Studies. 2002. *U.S. Materials Use Factsheet*. Available at: http://css.snre.umich.edu/css_doc/CSS05-18.pdf

[24] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life Cycle Assessment of Emissions and Sinks*. p. ES-1. Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

[25] Kolankiewicz and Beck. 2001. *Weighing Sprawl Factors in Large U.S. Cities: Analysis of U.S. Bureau of the Census Data on the 100 Largest Urbanized Areas of the United States*. Available at: http://www.sprawlcity.org/studyUSA

[26] U.S. EPA. 2003. *Beyond RCRA: Waste and Materials Management in the Year 2020*. Available at: http://www.epa.gov/epaoswer/osw/vision.pdf. "Sustainable Materials Management: The Road Ahead" builds on this report and is scheduled to be published in Fall 2009

Using materials management approaches to help reduce or avoid GHG emissions is consistent with EPA's vision and many of the strategies to increase the efficient and sustainable use of resources and reduce waste generation are described in *Beyond RCRA: Waste and Materials Management in the Year 2020*. Some of the strategies include reducing the amount of materials used to make products or perform services and influencing product design, use, and reuse capabilities to minimize raw material inputs, extend product life spans, and maximize the ease and frequency of subsequent product disassembly, recycling, and/or transformation for further productive use.[27] In addition to increasing material efficiency and reducing waste, materials management activities have the potential to significantly reduce GHG emissions, as described in the following sections.

Land management is a term used to describe separate or integrated strategies that influence how we manage and use land to provide open space and habitat, food, natural resources, and places for people to live, work, and recreate. For example, land management includes the practices of developing land and managing land for agricultural and forestry purposes. The way we manage our land directly influences GHG emissions related to agriculture, the built environment (e.g., residential and commercial emissions), electricity use, and transportation.

The concept of land management links directly to EPA's vision of preventing land contamination, in part, by encouraging smart growth,[28] improving chemical and waste management to prevent contamination, restoring contaminated and potentially contaminated land for reuse by society, and encouraging the sustainable reuse of property. Some land management approaches can also yield GHG emission reductions or can protect the carbon sink provided by U.S. land, which is further described in Section 2.

By taking advantage of opportunities presented by materials and land management, EPA and its partners can contribute to a reduction or avoidance of GHG emissions as well as improvement to public health and the environment.

Leveraging OSWER programs to achieve measurable climate change benefits in no way replaces or supersedes other OSWER program goals. Rather, this document promotes the recognition that materials and land management programs have significant climate benefits while yielding positive environmental, economic, and societal co-benefits in communities across the country.

In the case of materials management, the majority of GHG reduction benefits from recycling or waste prevention come from the energy savings from avoided resource extraction and materials processing.[29] This energy savings carries co-benefits of improvements in local air quality. Similarly, the conservation of raw material reduces environmental degradation and water pollution from mining, logging, and oil extraction.

Materials management options often also have economic benefits for communities. For example, recycling a ton of material creates many more jobs than sending the same material to a landfill

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[27] Ibid.

[28] For more information on the definition of smart growth, including the ten basic principles of smart growth, and smart growth approaches, refer to: http://www.epa.gov/smartgrowth.

[29] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*. Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

because of the labor required to collect, sort, and process the recyclables.[30] Recycling, reuse, deconstruction, and remanufacturing shift the value added in the economy from highly mechanized, environmentally harmful extraction industries, to labor-intensive, local industries.[31,32]

Land management options to reduce emissions also have many co-benefits. A number of studies have shown substantial beneficial effects of brownfields redevelopment for local communities, including job creation, increased property values, tax revenues for local governments, preservation of greenspace, and social benefits.[33,34] Other research has shown that brownfields redevelopment, as a component of urban redevelopment, reduces local vehicle miles traveled and is associated with lower building energy use,[35] both of which lead to improvements in urban air quality in addition to GHG reductions.

The co-benefits to communities of materials and land management strategies make them attractive as GHG reduction options. Unlike many GHG mitigation options, they are also largely under state and local influence. States and communities can use these tools to reduce their carbon footprints and meet state or local GHG reduction targets.

The purpose of this document, *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices*, is to increase the understanding of how materials and land management practices relate to GHG emissions and show a new way of thinking about materials and land management as part of the solution to the climate change. This document presents EPA's research to date. As we develop programs and policies with our partners, more detailed studies that account for economic, technical, and institutional limitations and opportunities will be needed. In addition, we will share information on the mitigation impacts of current materials and land management programs on GHG emissions and ultimately develop more specific approaches to implement materials and land management activities that could achieve GHG emission reductions.

The remainder of this document is organized into the following sections. Section 2 presents annual GHG emissions in the United States using two approaches. The sector-based approach allocates emissions to economic or end-use sectors including the electric power industry, transportation, industry, agriculture, commercial, and residential sectors. The systems-based approach relies on the same data, but apportions emissions to materials management, land management, and other systems to demonstrate the potential impact materials and land management have on total U.S. emissions. Section 3 presents research into the potential GHG reductions that could be achieved through a number of materials and land management approaches. Section 4 summarizes the report and describes the direction that future research may take. Finally, the document appendix (*Technical Support for Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices*) presents the data sources and methodology used to develop this report.

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[30] ETAAC. Recommendation of the Economic and Technology Advancement and Advisory Committee (ETAAC). California Air Resources Board. February, 2008. Available: http://www.arb.ca.gov/cc/etaac/ETAACFinalReport2-11-08.pdf

[31] Northeast Recycling Council. "Recycling Economic Information Study Update: Delaware, Maine, Massachusetts, New York, and Pennsylvania." February, 2009.

[32] Institute for Local Self Reliance. "Waste to Wealth." Accessed July, 2009. Available: http://www.ilsr.org/recycling/recyclingmeansbusiness.html

[33] Wernstedt, Kris. 2004. "Overview of Existing Studies on Community Impacts of Land Reuse." National Center for Environmental Economics Working Paper #04-06. U.S. EPA.

[34] Paull, Evans. 2008. "The Environmental and Economic Impacts of Brownfields Redevelopment." Northeast-Midwest Institute. Available at: http://www.nemw.org/images/stories/documents/EnvironEconImpactsBFRedev.pdf

[35] Paull, Evans. 2008; updated June 11, 2009. "Energy Benefits of Urban Infill, Brownfields, and Sustainable Urban Development: A Working Paper." Available at: http://www.nemw.org/images/stories/documents/energy_benefits_infill_brfds_final_12-08.pdf

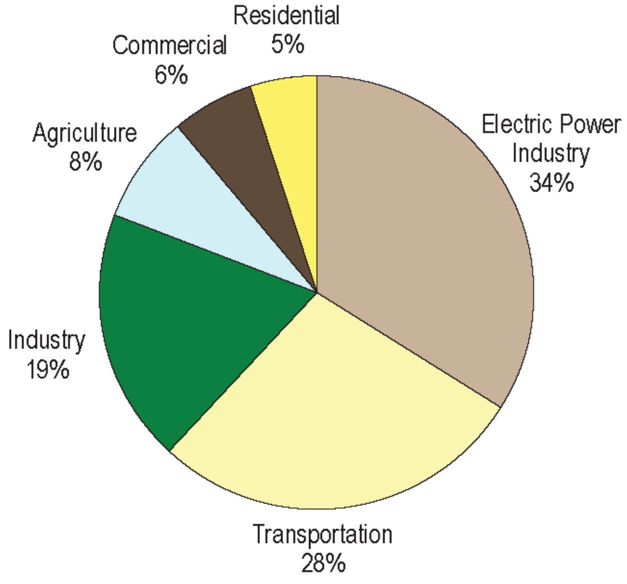
SECTION 2
UNDERSTANDING U.S. GHG EMISSIONS

The United States annually reports its GHG emissions in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[36] The Inventory comprehensively quantifies our country's primary anthropogenic sources and sinks of GHG emissions using methodologies developed by the International Panel on Climate Change (IPCC), in accordance with United Nations Framework Convention on Climate Change (UNFCCC) national inventory reporting guidelines, and allows a comparison of the relative contribution of different emission sources and gases to climate change. In 2006, the United States had total emissions of 7,054 million metric tons of carbon dioxide equivalent (MMTCO$_2$E) from a wide range of sources.

SECTOR-BASED VIEW OF U.S. GHG EMISSIONS

In addition to a detailed accounting of emissions by source category, the information in the Inventory is also summarized by economic sector. In 2006, 34% of emissions were allocated to the Electric Power Industry, 28% to Transportation, 19% to Industry, 8% to Agriculture, 6% to Commercial, and 5% to Residential (see Figure 1).[37]

Figure 1
Sector-Based View of U.S. GHG Emissions (2006)



This figure reflects data from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* (U.S. EPA, 2008), Table 2-12. This figure excludes emissions from U.S. territories, which are not allocated to economic sectors.

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[36] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html. This report relies on the Inventory data published in 2008; a more recent version, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, was published in 2009 and can be found at http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[37] Emissions from U.S. territories are categorized as a separate sector, totaling 1% of total U.S. emissions; because these emissions are not allocated to economic sectors, they are not described here. U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2006*. Executive Summary, Table ES-7: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO$_2$ Eq.) Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html

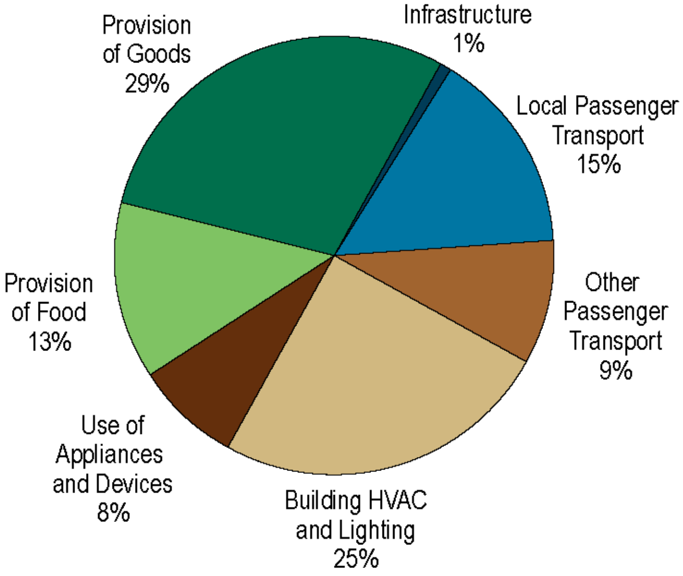
A sector-based view of emissions, because it describes where emissions are released, can be helpful for framing end-of-pipe strategies, such as carbon capture and sequestration at power plants or biofuel substitution in vehicles. It is also helpful for framing technology substitutions that affect a particular sector, such as hybrid-electric vehicle engines or solar electricity generation.

A sector-based view of emissions, however, does not show the role that materials and land management play in GHG emissions. The emissions associated with the goods we create and consume, for example, are embedded in portions of the Industry (e.g., mining and manufacturing), Electric Power Industry (e.g., electricity use), Commercial (e.g. disposal of wastes), and Transportation (e.g., freight) sectors. The emissions related to how and where we develop land are associated with the Transportation (e.g., vehicle miles traveled), Residential (e.g., subdivision development), Commercial (e.g., building construction), and Electric Power Industry (e.g., electricity use) slices of the pie chart in Figure 1.

SYSTEMS-BASED VIEW OF U.S. GHG EMISSIONS

To better understand and describe the connections between materials and land management and climate change, Figure 2 shows U.S. GHG emissions using a systems-based perspective. This perspective groups major GHG emission sources by system, where each system represents and comprises multiple parts of the economy that work together to fulfill a particular need. For example, the Provision of Food system includes emissions from the Electric Power Industry, Transportation, Industry, and Agriculture sectors associated with growing, processing, transporting, and disposing of food.

Figure 2
Systems-Based View of U.S. GHG Emissions (2006)



This figure reflects the same GHG emissions data shown in Figure 1, using a systems-based approach, as described in Appendix A. Emissions from U.S. Territories are not included in this figure.

Figure 2 shows the same 2006 GHG emissions that are shown in Figure 1, but allocates the emissions into systems that have been selected to help illustrate the GHG emissions associated with materials and land management: Provision of Food, Provision of Goods, Infrastructure, Local Passenger

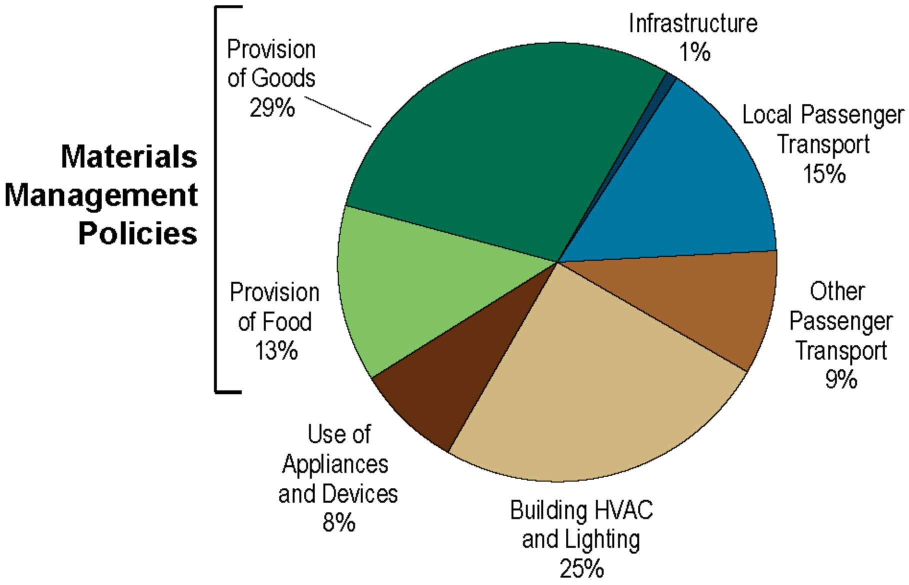
Transport, Other Passenger Transport, Building Heating, Ventilation, Air-Conditioning (HVAC) and Lighting, and Use of Appliances and Devices.[38] This is helpful for framing opportunities to reduce GHG emissions through prevention-oriented mitigation strategies that act across an entire system, complementing the sector-based allocation shown in Figure 1.

Both the sector-based and systems-based views provide critically important insights for successful climate mitigation strategies.

Materials Management

Two of the slices in the systems-based pie chart represent emissions related to materials management, as shown in Figure 3: Provision of Goods and Provision of Food.[39] The materials management section of the pie chart represents U.S. emissions related to the extraction or harvest of materials (e.g., mining, forestry, and agriculture), the production and transport of goods and food, the provision of services, and ultimately the disposal of goods and food (see Box 1). Every step in this material flow results in environmental impacts, including GHG emissions.

Figure 3
Systems-Based View of U.S. GHG Emissions (2006):
Highlighting Materials Management



This figure reflects the GHG emissions data shown in Figure 1, using a systems-based approach, as described in Appendix A. Emissions from U.S. Territories are not included in this figure.

The **Provision of Goods** slice of the pie chart represents the emissions associated with the goods and services we create, transport, and dispose of on a daily basis. It is composed of a portion of emissions from all economic sectors in Figure 1, except Agriculture. Its components include most of the direct emissions from the industrial sector (with some exceptions, such as food and fuel processing[40]),

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[38] See Appendix A for a detailed description of the methodology used to develop the pie charts presented in Figures 2-4.

[39] See Appendix A for a detailed description the emissions associated with Provision of Goods and Provision of Food.

[40] Some industrial sector emissions are allocated to other slices, most notably food processing emissions (allocated to Provision of Food) and most emissions from extraction and processing of fossil fuels. Emissions from petroleum and natural gas extraction and refining, natural gas distribution,

emissions from industrial sector electricity use (with the same exceptions), transport of non-food goods (freight), landfill methane, substitution of ozone-depleting substances, industrial wastewater treatment, and residential soil fertilizer. In total, the Provision of Goods is estimated to account for 2,040 $MMTCO_2E$, or 29%, of 2006 U.S. GHG emissions.[41]

Box 1: Impact of Materials Management on U.S. GHG Emissions

The extraction of natural resources; the production, transport, and disposal of goods, and the provision of services account for an estimated 29% of 2006 U.S. anthropogenic GHG emissions. In addition, the production, transport, and disposal of food account for 13% of 2006 U.S. anthropogenic GHG emissions.

Combined, materials management is associated with an estimated 42% of 2006 U.S. anthropogenic GHG emissions.

The **Provision of Food** slice of the pie chart represents emissions associated with food production, processing, transport, and disposal, and is composed of a portion of emissions from all economic sectors except Residential. It includes direct emissions from agricultural sources, agricultural sector electricity use, transport of food-related products (freight), wastewater treatment (except for emissions from pulp and paper manufacturing and ethanol production), the consumption of fuel and electricity in food and beverage processing, leaks of hydrofluorocarbons (HFCs) from refrigeration equipment, and composting. Carbon sequestration on agricultural lands is captured in the land sink discussed below. Provision of Food is estimated to account for 895 $MMTCO_2E$, or 13%, of 2006 U.S. GHG emissions.[42]

Note that the U.S. GHG emissions presented in Figures 1 through 5 represent emissions that are released domestically. Emissions associated with goods and services that are produced in other countries (i.e., emissions associated with extraction of raw materials, processing, and production of goods and services outside the United States) but consumed in the United States are not captured in the U.S. Inventory, and therefore are not reflected here. Correspondingly, the emissions associated with goods and services produced in the United States that are exported for consumption in other countries are included. Many materials management strategies reduce emissions from production of goods outside the United States, but those potential reductions are not reflected in this document. If U.S. emissions were calculated using a total life cycle perspective, based on goods and services consumed rather than produced in the United States, the emissions associated with materials management would be greater than is shown due to the large quantity of goods that are imported.[43]

Land Management

The systems-based view also helps convey the effect land management has on U.S. GHG emissions. The land management portion of the pie chart shown in Figure 4 represents the emissions and sinks associated with land management activities in the United States, including emissions and sinks associated with the preservation of greenfields and changes to land use and land management, including land development, reuse, and restoration.

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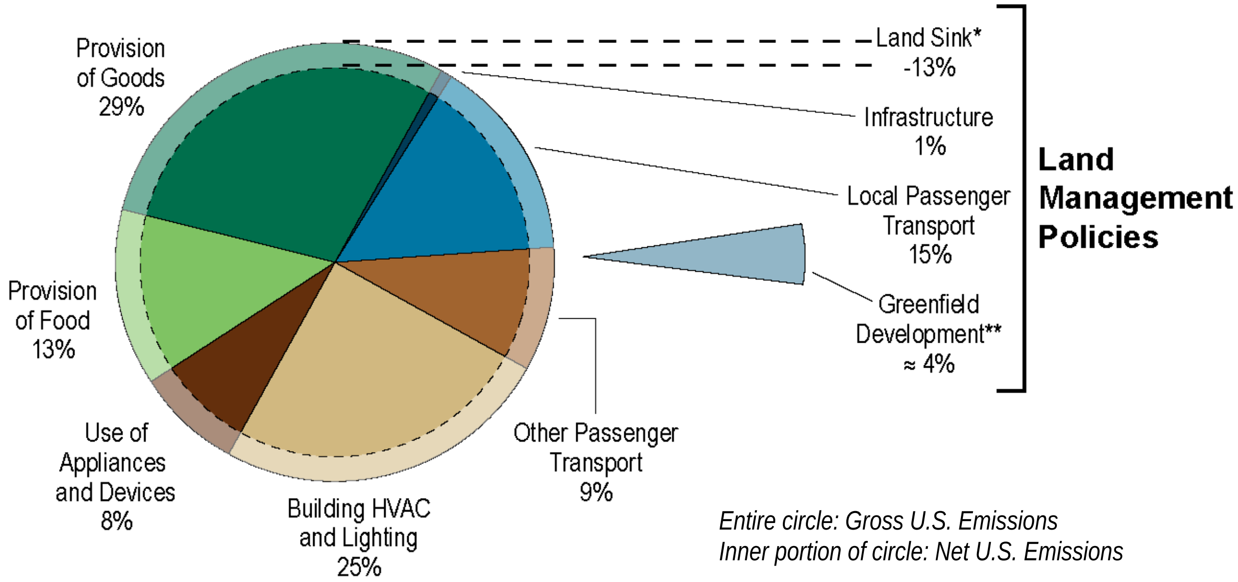
and coal mining were allocated according to their end use in terms of transportation or electricity use. A large share of petroleum refining emissions is allocated to Local Passenger Transport, for example.

[41] See Appendix A for an itemized breakdown of emissions associated with the Provision of Goods.

[42] See Appendix A for an itemized breakdown of emissions associated with the Provision of Food.

[43] Weber, Christopher L. and H. Scott Matthews. 2007. *Emissions Embodied in U.S. International Trade*. Environmental. Science and Technology. Vol. 41, No. 14. July 15, 2007. pp. 4875-4881.

Figure 4
Systems-Based View of U.S. GHG Emissions (2006):
Highlighting Land Management



This figure shows the same systems-based GHG emissions allocations as Figures 2 and 3, plus a depiction of the carbon sink provided by U.S. land and emissions from greenfield development, as described in Appendix A.

* The Land Sink, represented by the outer ring, offset the equivalent of 13% of total U.S. anthropogenic emissions in 2006. It is graphically represented here as a semi-transparent ring that erases a portion of emissions from all other slices shown in the pie chart. The entire pie chart represents total U.S. emissions in 2006; once the offset provided by the Land Sink is applied, the inner portion of the pie chart represents net U.S. emissions.

** Greenfield development represents emissions from land clearing (equivalent to roughly 4% of U.S. emissions in 2006); this calculation is not included in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, and is therefore depicted outside of the pie chart. It may include some overlap with the existing land sink value.

Land management emissions and sinks are depicted as four elements in the systems-based pie chart. The emissions sink provided by soil and growing vegetation in the United States is depicted as the outer ring of the pie chart (Land Sink). Also, there are two slices in the pie chart associated with land management: Infrastructure, which consists of life cycle GHG emissions from constructing and maintaining roads and water infrastructure, and Local Passenger Transport. Finally, an estimate of the emissions associated with Greenfield Development is depicted as a floating pie slice. Further description of these pie chart elements follows.

The **Land Sink**, shown as the outer ring in Figure 4, represents the amount of total U.S. emissions that are offset by the amount of carbon that is absorbed by soil and vegetation in the United States. The United States is among the top four countries in the world in terms of land mass. This land mass enables the storage and active absorption of carbon[44] in the soil, vegetation, and ground litter cover and is referred to as the Land Sink or land-based carbon sink in this document.

The amount of carbon dioxide equivalent that is stored by the land-based carbon sink is reported in the annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks* as a negative number because it offsets

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[44] Carbon sequestration is the process by which ambient CO_2 is absorbed and stored by vegetation, or other means, and removed from the atmosphere. For additional information, refer to: http://www.epa.gov/sequestration/

total U.S. emissions. The carbon sink is a net number. The magnitude given for the sink is net of two small sources of positive emissions from land and is dominated by the negative emissions from growing forests and net increases in forest area. We have included it in the systems-based analysis because it shows the scale of the land-based carbon sink compared with total GHG emissions and the importance of land management in carbon mitigation strategies. It is represented graphically in Figure 4 as a semi-transparent ring that erases, or takes away, emissions from all other slices shown in the pie chart. Therefore, the inner portion of the pie chart in Figure 4 represents *net* 2006 U.S. anthropogenic emissions (6,108 MMTCO$_2$E), while the entire pie chart represents *gross* 2006 U.S. emissions (6,992 MMTCO$_2$E).[45] The land-based carbon sink stores 884 MMTCO$_2$E, the equivalent of 13% of 2006 U.S. anthropogenic GHG emissions (see "Land Sink" in Figure 4 and Box 2).[46]

Infrastructure is the next element of Figure 4 associated with land management. This slice of the pie chart represents the emissions associated with the construction and maintenance of infrastructure, including highways, streets, bridges, tunnels, water, sewers, and pipelines. Infrastructure is part of the land management system because infrastructure construction and maintenance are intrinsically linked with land management. Developing greenfields requires infrastructure to connect newly developed land with existing development. Emissions from constructing new infrastructure can be substantially avoided by land reuse.[47] This slice includes both direct emissions from construction equipment and indirect emissions (e.g., from the production of concrete and the manufacturing of construction equipment used to produce infrastructure).[48] Approximately 72 MMTCO$_2$E, or 1% of total GHG emissions are associated with Infrastructure.

Box 2: Impact of Land Management on U.S. GHG Emissions

U.S. land provides a land-based carbon sink that absorbed approximately 884 MMTCO$_2$E in 2006, offsetting the equivalent of 13% of 2006 U.S. anthropogenic GHG emissions.

The emissions associated with infrastructure and local passenger transport accounts for 16% of 2006 U.S. anthropogenic GHG emissions. An additional 4% may be related to greenfield development.

Combined, land management is associated with an estimated 16% to 20%, of 2006 U.S. anthropogenic emissions, and an emission offset equivalent to 13% of 2006 U.S. anthropogenic emissions.

The next land management element of Figure 4 is **Local Passenger Transport**. The country's land development patterns strongly influence the number of vehicle miles traveled, and therefore, the GHG emissions from Local Passenger Transport.[49] This slice represents emissions associated with short-distance driving of personal vehicles, which increases as the area of developed land increases, as well as bus travel and commuter rail. The Local Passenger Transport slice of the systems-based pie chart is primarily composed of emissions from fuel combustion by passenger cars and light trucks making short trips (defined as less than 50 miles), as well as local bus and light rail emissions, and emissions from

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[45] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* p. ES-14. Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html. Total and net emissions values exclude emissions from U.S. territories of 62 MMTCO$_2$E (1%), which could not be disaggregated.

[46] Ibid, p. ES-14.

[47] U.S. EPA. October 1999. *The Transportation and Environmental Impacts of Infill Versus Greenfield Development: A Comparative Case Study Analysis.* Available at: http://www.epa.gov/smartgrowth/pdf/infill_greenfield.pdf; U.S. Department of Agriculture. June 2001. *Development at the Urban Fringe and Beyond: Impacts on Agriculture and Rural Land.* Agricultural Economic Report No. 803. Available at: http://www.ers.usda.gov/publications/aer803/aer803.pdf; Paull, Evans. 2008; updated June 11, 2009. "Energy Benefits of Urban Infill, Brownfields, and Sustainable Urban Development: A Working Paper." Available at: http://www.nemw.org/images/stories/documents/energy_benefits_infill_brfds_final_12-08.pdf

[48] See Appendix A for more detail on how the estimate of GHG emissions from infrastructure development to newly developed greenfield was derived.

[49] Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., and Chen, D. 2008. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Urban Land Institute. Washington, D.C.

extracting and processing fuels used for local passenger transport. The slice represents 1,019 $MMTCO_2E$, or 15% of 2006 U.S. emissions.[50]

The final land management element of Figure 4 is the additional slice outside the pie chart representing **Greenfield Development**. Each year, millions of acres of previously undeveloped or agricultural land ("greenfields") are developed,[51] resulting in GHG emissions from the carbon sink provided by U.S. land and vegetation. However, the GHG emissions associated with greenfield development are not currently calculated in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. Because these emissions are related directly to land cleanup, revitalization and reuse, a rough estimate was prepared for this report. This estimate accounts for forest, grassland, and agricultural land converted for an urban use and may include some overlap with the existing land sink value.

These emissions are shown as an additional slice outside the pie chart in Figure 4 because it represents an initial estimate that is not included in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* and, as calculated, would be in addition to the emissions shown in the rest of the pie chart.[52] The methodology used to develop this estimate is described in Appendix A. The preliminary estimate indicates emissions associated with the development of greenfields are on the order of 314 $MMTCO_2E$, or approximately 4%, of 2006 U.S. GHG emissions.[53]

Other

There are three additional systems that we have grouped under "Other" (see Figure 5). This category includes the Use of Appliances and Devices (8%), Building HVAC and Lighting (25%) and Other Passenger Transport (9%). While it can be argued that each of these slices are influenced by materials or land management, many of the associated mitigation approaches have been widely explored in other studies and are not the focus of this report. These slices are briefly described below.

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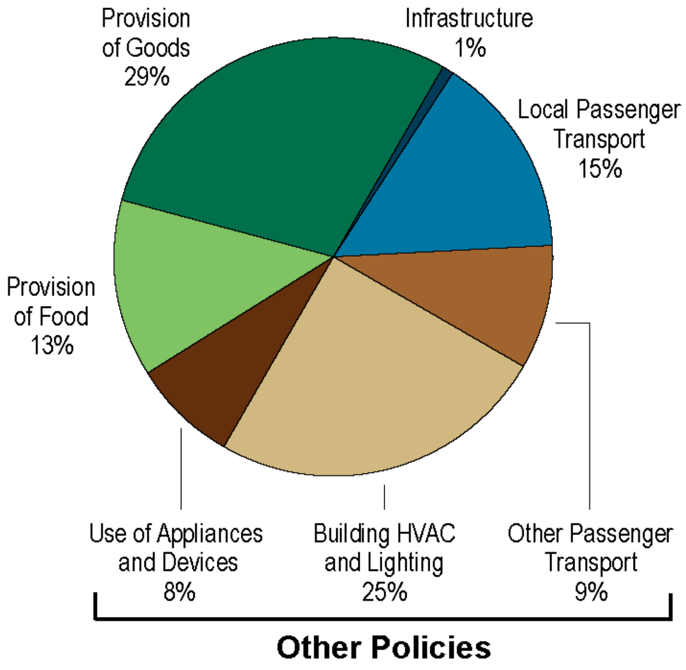
[50] See Appendix A for a detailed description the emissions associated with Local Passenger Transport.

[51] U.S. Department of Agriculture, Natural Resources Conservation Service. July 2007. *National Resource Inventory 2003 NRI: Land Use.* Available at: http://www.nrcs.usda.gov/technical/NRI/2003/Landuse-mrb.pdf

[52] There is also a higher degree of uncertainty associated with this estimate because it uses a rough, first pass methodology in absence of detailed supporting data.

[53] This estimate was based on methodologies and recommendations made by the Intergovernmental Panel on Climate Change in the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*. The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* also relies on this IPCC guidance. See Appendix A for a description of the methodology used to develop the estimate for greenfield development.

Figure 5
Systems-Based View of U.S. GHG Emissions (2006):
Highlighting Other Emissions



This figure shows the same systems-based allocation as Figures 2 through 4, highlighting the slices not associated with materials management or land management.

Use of Appliances and Devices includes emissions resulting from the electricity and fuel used by washing clothes, cooking, refrigeration,[54] and the use of office equipment, computers, and other appliances, as well as the industrial emissions associated with extracting and processing the associated fossil fuels. The life cycle associated with provision of goods includes emissions from the use of products, so it can be argued that emissions associated with this slice could be included in the Provision of Goods and/or Provision of Food slices under materials management. We present it as a separate slice for two reasons. First, the systems are partly chosen to represent the domain of a particular set of prevention-oriented mitigation opportunities. The opportunities to reduce emissions from the Use of Appliances and Devices—through improved energy efficiency or changes in consumer usage patterns for example—are different from most materials management opportunities discussed in this report, which reduce waste or promote materials efficiency. Second, energy efficiency opportunities to reduce GHG emissions have been widely explored elsewhere and this report aims to highlight the additional materials management opportunities that are less well-known. However, it should be noted that materials management, understood comprehensively, includes the use phase of products. Approximately 581 MMTCO$_2$E, or 8% of total GHG emissions are associated with the Use of Appliances and Devices.

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[54] Except for industrial cooking and refrigeration, which is included in Provision of Food. Includes residential and commercial sources only.

The **Building HVAC and Lighting** slice includes the emissions resulting from heating, cooling, ventilation, and lighting residential and commercial buildings, as well as industrial emissions associated with extracting and processing the associated fossil fuels.[55] Emissions from Building HVAC and Lighting are partially influenced by the type of materials and construction used in buildings, and so it can be argued that this slice should also be included under materials management. Alternately, since land use planning influences the types of buildings constructed and hence the energy used by them, it can also be argued that this slice could be included under land management.

Similar to Use of Appliances and Devices, we present it separately for two reasons. First, the kinds of prevention-oriented opportunities to reduce these emissions—building design which takes better advantage of natural light and climate control, or increased energy efficiency of buildings and lighting for example—are largely different from the types of materials and land management opportunities described in this report, which focus on waste prevention, materials efficiency, and land reuse. Second, opportunities to reduce GHG emissions associated with building energy use have been widely explored elsewhere and this report aims to highlight additional opportunities from materials and land management. However, it should be noted that materials management and land management, understood comprehensively, include the use phase of buildings. Approximately 1,719 $MMTCO_2E$, or 25% of total GHG emissions are associated with this slice.

Other Transportation Emissions are largely composed of emissions from long-distance passenger travel (90% of the remaining "other" transportation emissions), including emissions from aircraft, inter-city rail, inter-city buses, cars, and light trucks making long-distance trips, and upstream industrial sector fossil fuel combustion. Miscellaneous emissions, primarily from military aircraft and recreational vehicles, comprised the other 10% of this category. In all, non-local passenger transportation accounted for 666 $MMTCO_2E$, or 9% of US GHG emissions in 2006.[56] Land management policies have less of an effect on non-local transportation, which is why these emissions are presented separately. Prevention-oriented policies to reduce inter-city passenger transportation include activities which shift travel to lower-impact modes and promote more efficient loading or movement within modes.

Summary

The systems-based pie chart shown in Figures 2 through 5 provides a sense of the relative magnitude of emissions associated with materials and land management. By assessing U.S. GHG emissions from a systems perspective, it is evident that management of materials and land has a significant impact on the nation's total GHG emissions and sinks. As shown in Figures 3 and 4 and highlighted in Boxes 1 and 2, materials and land management activities combine to influence 58-62% of 2006 U.S. anthropogenic GHG emissions, while also offsetting 13% of 2006 U.S. anthropogenic GHG emissions.

Each slice of the systems-based pie chart presents opportunities for prevention- and systems-oriented strategies to reduce GHG emissions. Such strategies for reducing GHG emissions through materials and land management include materials efficiency, industrial ecology, green design, land revitalization, sustainable consumption, smart growth, pollution prevention, and design for environment.

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[55] Electricity use by commercial establishments such as supermarkets and restaurants is included in the Building HVAC and Lighting and Use of Appliances and Devices slices of the pie chart (as opposed to Provision of Food). Energy used by industrial buildings is included in Provision of Goods and Provision of Food.

[56] Percent of total rounded down from 10% to 9%, so that percentages sum to 100% in the systems-based pie charts.

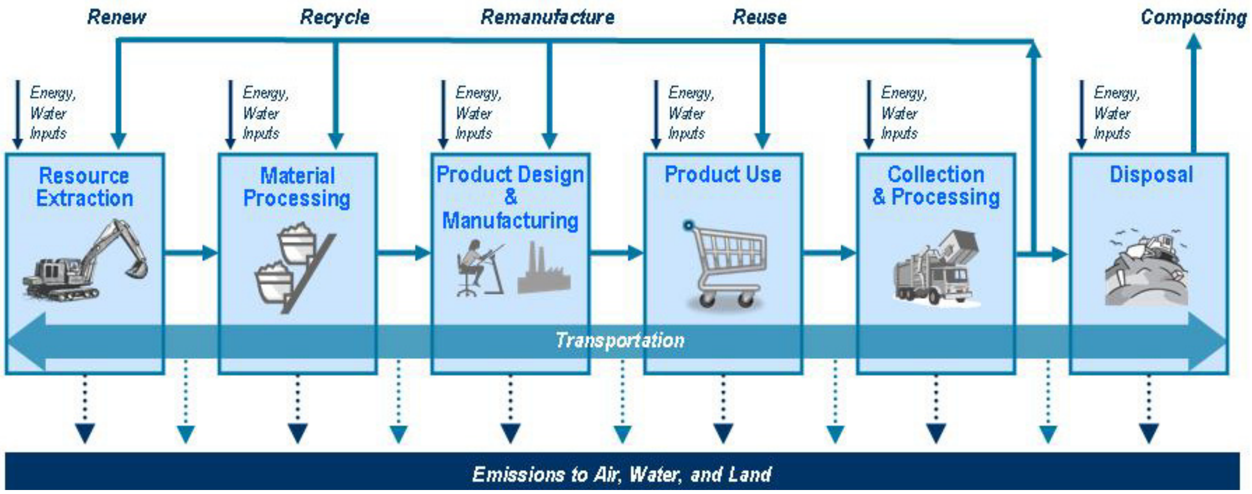
SECTION 3
POTENTIAL GHG REDUCTIONS THROUGH MATERIALS AND LAND MANAGEMENT

Materials and land management directly and indirectly impact 58-62% of total U.S. GHG emissions, and, therefore, provide many opportunities to reduce GHG emissions. This section presents some examples of materials and land management approaches that could result in significant emission reductions.

REDUCING GHG EMISSIONS THROUGH MATERIALS MANAGEMENT PRACTICES

Materials management is a term that describes how materials are managed as they flow through the economy—from resource extraction to product design and manufacture, transport, use, reuse, recycling, and end of life (see Figure 6). Taking a systems view of the impacts materials have throughout their life cycle allows for analysis to answer questions such as: Where in the materials life cycle does the greatest amount of GHG emissions occur? And where in the materials life cycle is the greatest opportunity to reduce GHG emissions?[57]

Figure 6
Flow of Materials



Materials management seeks the most productive use of resources and focuses broadly on impacts and policies relating to all of the stages of material flow. By considering the impacts throughout the entire life cycle, materials management works to reduce environmental impacts, both (1) directly at each stage and (2) indirectly at multiple stages by reducing the amounts of materials used, and thus reducing system-wide environmental impacts, including GHG emissions. Through materials management approaches, the same level of service can be provided while substantially reducing GHG emissions.

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[57] Life cycle assessment, a technique for evaluating all environmental impacts associated with a product throughout its life cycle, can be helpful framework in this type of systems analysis.

The waste management hierarchy is a framework that is helpful for understanding how materials management approaches can be used to influence materials as they flow through the material life cycle (see Box 3).[58]

Source reduction describes the practice of minimizing the use of raw material inputs and substituting reusable and more sustainable inputs to reduce environmental impacts and reduce waste. This may involve modifying material extraction and harvesting practices or improving product design and manufacturing practices, all of which can also significantly reduce GHG emissions.

Improving the durability, adaptability, and potential for products and their components to be reused can extend product life spans, requiring less material input and reducing waste and GHG emissions. For example, maximizing the ease and frequency of product disassembly, recycling, and/or transformation for further productive use can also yield significant benefits.

Box 3: Waste Management Hierarchy

Source reduction prevents the generation of waste and pollution. In the materials management framework, it is the reduction of the amount of materials entering the supply stream.

Reuse is the reuse of a product by its original user or someone else.

Recycling is a series of activities that includes collecting recyclable materials that would otherwise be considered waste, sorting and processing into raw materials such as fibers, and manufacturing raw materials into new products.

Energy recovery is the process of obtaining energy from waste through a variety of processes (e.g., combustion).

Disposal is the placement of waste on land or underground, including proper disposition of a discarded or discharged material.

In the product use stage, consumers can choose products and services that minimize GHG emissions and environmental impacts, and use those products and services in ways that minimize GHG emissions. After using products, consumers can reuse, recycle, or dispose of them. Reusing and repurposing products can decrease GHG emissions by avoiding the need to create new products. In addition, using recycled materials to create new products can reduce life cycle GHG emissions. When neither reuse nor recycling is possible and products are disposed, proper disposal practices can mitigate GHG emissions and environmental impacts and recovery of the energy contained in materials can reduce GHG emissions by offsetting fossil fuel combustion.[59]

Throughout the material flow, using improved distribution practices to reduce transportation requirements, and promoting the reuse and recycling of products and their components through closed-loop or other approaches can further reduce waste and GHG emissions.

Significant GHG emission reductions have already been achieved in the United States by EPA, states, local governments, and stakeholders through numerous materials management-related activities (see Box 4).[60]

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[58] For additional information on the Waste Management Hierarchy, refer to: http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm.

[59] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life Cycle Assessment of Emissions and Sinks*. Exhibit ES-4 (Net GHG Emissions from Source Reduction and MSW Management Options (MTCE/Ton)), and p. 13. Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

[60] The GHG emissions estimates in Box 4 rely on the following data. (1) Hazardous and Non-hazardous Waste Minimization: U.S. EPA, Office of Solid Waste and Emergency Response. November 2007. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006*, p. 1. (2) Waste to Energy: U.S. EPA, Office of Solid Waste and Emergency Response. November 2007. *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006*, p. 8. (3) EPA's Resource Conservation Challenge: Partnership Programs, Municipal Solid Waste, WasteWise: U.S. EPA. October 2006. *WasteWise 2006 Annual Report*. p. 1. Available at: http://www.epa.gov/waste/partnerships/wastewise/pubs/report06.pdf. (4) EPA's Resource Conservation Challenge: Partnership Programs, Green Initiatives-Electronics, Plug-in to eCycling: The information is based on partner reported amounts of e-waste recycled in 2007. (5) EPA's Resource Conservation Challenge: Partnership Programs, Industrial Materials Recycling, Coal Combustion Products Partnership (C2P2): American Coal Ash Association. 2001. *ACAA 2001 Coal Combustion Products Survey;* Industrial Materials Recycling: American Coal Ash Association. 2006. *ACAA 2006*

Box 4: Ongoing Contributions and Collaborations to Reduce GHG Emissions through Materials Management

Hazardous and Non-hazardous Waste Minimization

The nation's recycling rate has increased from 29% in 2000 to 32.5% in 2006. This increase is based in part on the efforts of local, state, and federal waste reduction programs. In 2006, U.S. municipal solid waste recycling resulted in the GHG emissions avoidance of nearly 183 $MMTCO_2E$.

Waste to Energy

In 2006, waste-to-energy recovery systems combusted 31.4 million tons of MSW, thereby avoiding GHG emissions of 17.1 $MMTCO_2E$.

EPA's Resource Conservation Challenge: Partnership Programs

Municipal Solid Waste: WasteWise

In 2005, EPA's WasteWise partners reported source reduction and recycling activities that resulted in an avoidance of 27 $MMTCO_2E$ in GHG emissions.

Green Initiatives-Electronics: Plug-in to eCycling

In 2007, Plug-in to eCycling partners recycled or reused over 47 million pounds of electronics from consumers, resulting in approximately 0.13 $MMTCO_2E$ in GHG emissions avoided.

Industrial Materials Recycling: Coal Combustion Products Partnership (C2P2)

Between 2001 and 2006, C2P2 helped increase the recycling of coal combustion ash from 32% to 43%, resulting in 13 $MMTCO_2E$ in GHG emissions avoided.

To further illustrate some of the potential opportunities that materials management approaches provide for reducing GHG emissions, this analysis presents several *total technical potential* scenarios. Total technical potential scenarios are defined and described in Box 5.

Box 5: Total Technical Potential

The term **total technical potential refers to the estimated GHG emission reductions that would occur if the scenarios presented were achieved, setting aside economic, institutional, or technological limitations.**

Such scenarios are a common first step in climate policy analysis and allow for the examination of the GHG reduction potential of various mitigation strategies. These total technical potential scenarios are useful for scoping the order-of-magnitude impact of an activity and for identifying areas of promise for more detailed analysis. These scenarios suppose a change from current U.S. business-as-usual practices and provide an estimate of the potential climate-related benefits from those changes (e.g., reduction in GHG emissions measured in $MMTCO_2E$). Some scenarios represent the GHG emission reduction that could be achieved in addition to existing materials management practices (e.g., reducing packaging by 50%), while others represent the GHG emission reduction that could be achieved from existing materials management practices that are enhanced (e.g., recycle 100% of construction and demolition debris). It should be noted that these reduction rates do not represent EPA goals or targets.

The scenarios selected for this document represent a range of potential reductions (e.g., 0.2 to 2,200 $MMTCO_2E$). The majority of hypothetical reductions are on the same order of magnitude as individual options identified in climate change mitigation analyses conducted by others (e.g., see McKinsey and Company, "Reducing U.S. GHG Emissions: How Much and at What Cost?" (2007)). For at least one of these scenarios, landfill methane capture, economic analysis has also been performed which found significant lower-cost mitigation potential (e.g. U.S. EPA, "Global Mitigation of Non-CO_2 Greenhouse Gases." Report 430-R-06-0050.). For consistency, only the technical potential is shown here.

These scenarios can be considered a first-step analysis for identifying areas of opportunity for EPA and its partners. As we consider developing programs and policies, more detailed studies that account for economic and practical limitations and opportunities will be needed. The scenarios suggest how to direct these future efforts to pursue options with the largest impact. Appendix A provides additional details about the data sources, assumptions, and methodologies used to conduct these analyses.

Coal Combustion Products Survey. These data sources, along with the following tools, were used to calculate the GHG emissions estimates in Box 4: U.S. EPA. March 2009. *Greenhouse Gas Equivalencies Calculator*. U.S. EPA. August 2008. *WAste Reduction Model (WARM)*. Fogt, Robert. 2008. *Online Conversion Tool for Energy*. The University of Tennessee, Knoxville, Center for Clean Products. *Electronics Environmental Benefits Calculator*. Version 1.1.

Potential GHG Emissions Reductions from Materials Management

Because materials management is estimated to influence 42% of total 2006 U.S. GHG emissions, improved materials management practices throughout the material flow can have a significant impact on U.S. GHG emissions. The following total technical potential scenarios provide illustrative examples of how materials management activities could yield significant GHG emission reductions.

These materials management total technical potential scenarios include life cycle GHG emissions. These scenarios represent the estimated emission reductions that would occur if the scenarios presented were achieved, setting aside economic or practical limitations. They do not represent EPA goals or targets. Major data sources for the technical potential calculations include the EPA reports *Solid Waste Management and Greenhouse Gases: A Life Cycle Assessment of Emissions and Sinks*[61] and *Municipal Solid Waste in the United States: 2006 Facts and Figures*,[62] as well as EPA's WAste Reduction Model (WARM) and a variety of other reports. For further explanation of how the following estimates were developed, refer to Appendix A.

The total technical potential scenarios provided here are not representative of all possible approaches to reduce GHG emissions through materials management. Many of these scenarios focus on the waste stream because the data are limited on materials management strategies that focus on other points in the materials flow. As further research is completed, additional total technical potential scenarios will be developed to understand the GHG emission reductions that could be achieved throughout the materials flow. Potential reductions from some activities are summarized in Box 6.

Box 6: Summary of Total Technical Potential Scenarios

Source Reduction		Estimated GHG Emission Benefit*	
Reduce packaging use by:[63]	50%	40—105	MMTCO$_2$E/yr
	25%	20—50	MMTCO$_2$E/yr
Reduce use of non-packaging paper products by:[64]	50%	20—70	MMTCO$_2$E/yr
	25%	10—35	MMTCO$_2$E/yr
Extend the life of personal computers by:	50%	25	MMTCO$_2$E/yr
	25%	15	MMTCO$_2$E/yr
Reuse/Recycling			
Increase recycling of construction and demolition debris to:	100%	150	MMTCO$_2$E/yr
	50%	75	MMTCO$_2$E/yr
	25%	40	MMTCO$_2$E/yr
Increase national MSW recycling and composting rate from 2006 rate (32.5%) to:	100%	300	MMTCO$_2$E/yr
	50%	70—80	MMTCO$_2$E/yr
Increase composting of food scraps from 2006 rate (2%) to:	100%	20	MMTCO$_2$E/yr
	50%	10	MMTCO$_2$E/yr
	25%	5	MMTCO$_2$E/yr

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[61] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life Cycle Assessment of Emissions and Sinks*. Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

[62] U.S. EPA, Office of Solid Waste. 2007. *Municipal Solid Waste in the United States: 2006 Facts and Figures*. Available at: http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

[63] This total technical potential scenario assumes a similar level of product protection is possible with reduced packaging.

[64] Non-packaging paper products include magazines and third class mail, newspaper, office paper, phonebooks, and textbooks.

Box 6: Summary of Total Technical Potential Scenarios

Energy Recovery / Disposal		Estimated GHG Emission Benefit	
Combust percentage of currently landfilled MSW:[65, 66]	100%	70—120	MMTCO$_2$E/yr
	50%	35—60	MMTCO$_2$E/yr
	25%	20—30	MMTCO$_2$E/yr
Combust MSW remaining if national recycling rate is increased to 50%:		65—110	MMTCO$_2$E/yr
Capture percentage of currently emitted methane at U.S. landfills for electricity generation:	100%	150	MMTCO$_2$E/yr
	50%	70	MMTCO$_2$E/yr
	25%	35	MMTCO$_2$E/yr

* Most of the total technical potential scenarios presented in this table have been rounded to one significant figure. See Appendix A for more detail on these estimates.

REDUCING OR AVOIDING GHG EMISSIONS THROUGH LAND MANAGEMENT PRACTICES

Land management describes how we manage and use land to provide open space and habitat, food, natural resources, and places for people to live, work, and recreate. EPA promotes integrated land management strategies that use land as productively and sustainably as possible by promoting smart growth, preventing and minimizing the occurrence of contamination and by cleaning up, reusing, and restoring contaminated land for beneficial reuse by communities.[67]

As described in Box 7, land management has three key components: land protection, sustainable land use, and land revitalization. Similar to the materials management approaches that can be used in the material flow, land management approaches can be used to reduce GHG emissions by improving practices within or across each of these components. Land protection practices limit how much land is contaminated each year. When land is contaminated, it should be cleaned up to levels protective of human health and the environment.

Box 7: Land Management Approaches

Land Protection: prevent land from becoming contaminated.

Sustainable Land Use: use of land in such a way that preserves its value for future uses. Preserving pristine land resources minimizes greenspace development.

Land Revitalization: cleanup, ecological restoration, and sustainable reuse of contaminated land while avoiding the development of greenfields.

Sustainable land use practices include those that promote the sustainable use and development of land (including managing land for agricultural and forestry purposes), and minimizing greenfield development. Between 1982 and 2003, the U.S. population increased by 25%.[68] During the same period, the amount of developed land increased by 48%—almost double population growth.[69] As the amount of greenfields (or previously undeveloped land) that is developed increases, our population becomes more dispersed and people drive longer distances between home, work, and recreational locations. During this same period of time, U.S.

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[65] Based on the WARM Model, combustion with energy recovery has lower GHG emissions than landfilling on average, but actual emissions vary based on local conditions (e.g., the rate of methane recovery varies at individual landfills).

[66] The Council of the European Union recently designated energy-efficient waste incineration a recovery operation. The provision was adopted to "promote resource efficiency, thus reducing the consumption of fossil fuels" (PE-CONS 3646/08, October 2, 2008).

[67] For more information on smart growth and revitalizing contaminated land, refer to: http://www.epa.gov/smartgrowth and http://www.epa.gov/oswer/cleanup/index.html.

[68] U.S. Census. Available at: http://www.census.gov/

[69] U.S. Department of Agriculture, Natural Resources Conservation Service. July 2007. *National Resource Inventory 2003 NRI: Land Use.* p. 5. Available at: http://www.nrcs.usda.gov/technical/NRI/2003/Landuse-mrb.pdf

vehicle miles traveled increased by 42%, which again is higher than the rate of population growth and due largely to the increase in developed land.[70] Despite improvements made in vehicle fuel efficiency since the 1970s, GHG emissions from the transportation sector have increased in recent years, in part due to the increase in total vehicle-miles traveled.[71]

Smart growth approaches—such as reuse of property; infill, compact, and mixed-use development; and the cleanup and redevelopment of contaminated property—reduce development pressure on greenfields. Compact, mixed-use development makes it easier for residents to walk, bike, take transit, or drive shorter distances, which helps reduce vehicle-miles traveled and hence the GHG emissions associated with local travel. In addition, more sustainable land use and development at the local and state levels that prioritizes energy efficiency, reduced energy consumption, and reduced material consumption in building and infrastructure construction can further reduce GHG emissions.

Land revitalization practices promote the cleanup and reuse of contaminated land. By considering the impact of land management throughout its life cycle, the United States can realize significant reductions in GHG emissions. Decisions at the local, state, or federal level related to the cleanup, restoration and/or reuse of contaminated land (i.e., land revitalization) can also reduce GHG emissions. OSWER's role in land management is focused on preventing land from becoming contaminated and on the cleanup and reuse of land that has been contaminated. Through these programs, EPA currently tracks more than 488,000 contaminated or potentially contaminated sites covering almost 15 million acres across the country.[72] Many of these sites require some type of cleanup involving EPA and/or its federal, state, tribal, and local partners before the property can be reused. To date, EPA has helped make more than 917,000 acres of previously contaminated land ready for reuse.[73] However, it should be noted that EPA does not determine the new use of EPA-tracked sites; reuse decisions for contaminated land, including EPA-tracked contaminated land, are made by individual property owners and in accordance with local and state, tribal, and federal land use regulations and any requirements of the applicable cleanup program.

EPA and other organizations involved with cleaning up contaminated land may find opportunities to employ cleanup techniques that provide an equivalent level of environmental and human health protection while emitting lower amounts of GHGs through: 1) optimizing remedies and treatment systems both for new and existing remedies; 2) using alternative energy derived from cleaner and renewable energy sources; and 3) accounting for the technical needs of potential reuse options and incorporating them throughout the cleanup processes to facilitate sustainable reuse of the property and preservation of greenfields.[74]

Sequestering carbon on these sites is another potential benefit from some cleanup and reuse activities—particularly on former mine lands. At some sites, organic soil amendments can be used to remediate the site, boosting the amount of carbon sequestered in the soil and enhancing vegetation

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[70] American Association of State Highway and Transportation Officials. April 2008. *Primer on Transportation and Climate Change.* pp. 27-28. Available at: http://downloads.transportation.org/ClimateChange.pdf

[71] Ibid.

[72] U.S. EPA. March 17, 2009. *OSWER Cross-Program Revitalization Measures*, Table 1. Available at: http://www.epa.gov/LANDREVITALIZATION/docs/cprm_report_031709.pdf

[73] Ibid.

[74] Remedy selection is not based on GHG emissions, although GHG emissions may be one of many factors assessed at sites using green remediation practices.

growth.[75] This remediation approach also provides a use for some organic soil amendments such as biosolids which may otherwise be a waste product.

Land cleanup activities may also provide recycling opportunities to further bolster EPA's approaches to materials and land management. For example, reusing and recycling construction and demolition debris from buildings on contaminated land is another effective materials and land management practice; this practice not only reuses both materials and land, but also prevents other land from being used for the disposal of construction and demolition debris.

After cleanup is complete, sustainably reusing land protects the land-based carbon sink, by providing sites that can be reused for development, instead of developing greenfields. Reusing these restored properties can also reduce GHG emissions associated with the infrastructure expansion needed to connect newly developed greenfields to already developed areas. Policies that promote land reuse in place of new land development and denser mixed-use development—key aspects of smart growth—will avoid the majority of infrastructure and bio-carbon emissions. Sites can also be ecologically restored to increase the amount of undeveloped land and expand the land-based carbon sink.

In addition, several EPA programs focus on sustainable cleanup and redevelopment of contaminated land, including environmentally responsible landscaping, energy efficient structures, green buildings, and green remediation,[76] which can all further reduce GHG emissions. Many contaminated properties also have renewable energy development potential and are located near existing utility infrastructure.[77] And of course, preventing contamination in the first place avoids the need for cleanup activities or greenfield development. See Box 8 for examples of land management approaches that help reduce GHG emissions.[78]

Box 8: Ongoing Contributions and Collaborations to Reduce GHG Emissions – Land Management

Carbon Sequestration: EPA is studying the potential carbon sequestration that occurs when soil amendments are used to remediate sites.

Land Revitalization: To date, EPA has helped make more than 917,000 acres of previously contaminated lands ready for anticipated use, reducing pressure on greenfields and helping preserve the land-based carbon sink. EPA is promoting the development of renewable energy resources as one particularly promising land revitalization strategy with multiple environmental benefits.

Smart Growth: Smart growth has been shown to reduce household vehicle miles traveled by 20-40% compared with conventional development practices. For example, residents of Atlantic Station, a noted smart growth development, drive an average of 13.9 miles per day, compared to a regional average of 33.7 miles per day.

Green Remediation: Green remediation practices are being employed at contaminated sites, which can reduce GHG emissions. For example, some remediation projects use solar energy to operate ground water pump and treat systems; others are reducing construction engine idling time, and using alternative fuels to reduce GHG emissions.

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[75] U.S. EPA, Office of Solid Waste and Emergency Response. December 2007. *The Use of Soil Amendments for Remediation, Revitalization, and Reuse*. EPA 542-R-07-013. Available at: http://www.clu-in.org/download/remed/epa-542-r-07-013.pdf

[76] Remediation activities protect human health and the environment; green remediation seeks to reduce that environmental footprint of the cleanup activities themselves, for example by using cleaner diesel that reduce local air emissions, using electricity generated from renewable sources that create fewer life cycle GHGs, and conserving water and material resources. Available at: http://www.clu-in.org/greenremediation/.

[77] For further description of opportunities for siting renewable energy on EPA tracked contaminated land, refer to: http://www.epa.gov/renewableenergyland/index.htm

[78] Land Revitalization Example: U.S. EPA, Office of Solid Waste and Emergency Response. March 17, 2009. *OSWER Cross-Program Revitalization Measures*, Table 1. Available at: http://www.epa.gov/landrevitalization/docs/cprm_report_031709.pdf. Smart Growth Example: Jacoby Development, Inc. February 15, 2008. *Atlantic Station: 2008 Project XL Report*, Vehicle Miles Traveled for Residents and Employees. Available at: http://www.atlanticstation.com/concept_green_projectXL08.php#Anchor-ENVIRONMENTAL-37516

These land management processes exemplify cross-media synergies that will help EPA and its partners continue to achieve greater emissions reductions. In short, there are many opportunities for reducing GHG emissions by considering how and where we use land.

Potential GHG Emissions Reduced or Avoided from Land Management

There are many ways that EPA's land management practices can be leveraged to achieve GHG emission benefits. The following total technical potential scenarios show potential for substantial emission reductions or avoidance. As noted in Box 5, these total technical potential scenarios do not represent EPA goals or targets. Instead, these hypothetical examples are provided to show the magnitude of GHG emissions reductions that are possible through enhanced land management practices.[79] These estimates represent direct GHG emission benefits, and do not include life cycle emissions in all cases.

Because land management is estimated to affect 16-20% of total U.S. emissions as well as the land-based carbon sink that offsets the equivalent of 13% of 2006 U.S. anthropogenic emissions, there exists a significant opportunity to identify additional land management approaches to reduce GHG emissions. Although not presented as a complete technical potential scenario, the greenfield development slice can roughly be considered the potential reduction from shifting all greenfield development to land reuse and compact development. The following are examples of land management approaches that could be employed to achieve reductions in GHG emissions. Again, the total technical potential scenarios provided here are not representative of all of the possible approaches that could be used to reduce GHG emissions through land management. As further research is completed, additional total technical potential scenarios will be developed to illustrate the GHG emission reductions that could be achieved through land management. Potential reductions from some activities are summarized in Box 9.

Box 9: Summary of Total Technical Potential Scenarios

Land Revitalization [80]		Estimated GHG Emission Benefit
Shift 60% of expected new development to compact development patterns:[81]		79 $MMTCO_2E/yr$
Reuse percentage of qualifying EPA-tracked contaminated land for utility-scale solar:[82]	100%	2,200 $MMTCO_2E/yr$
	50%	1,100 $MMTCO_2E/yr$
	25%	540 $MMTCO_2E/yr$
Reuse percentage of qualifying EPA-tracked contaminated land for community and utility-scale wind:[83]	100%	40 $MMTCO_2E/yr$
	50%	20 $MMTCO_2E/yr$
	25%	10 $MMTCO_2E/yr$
Reduce electricity use for the most energy-intensive treatment technologies at National Priorities List sites by:	100%	0.4 $MMTCO_2E/yr$
	50%	0.2 $MMTCO_2E/yr$
	25%	0.1 $MMTCO_2E/yr$

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[79] See Appendix A for a detailed description of the methodology used to develop the materials management GHG emission reduction estimates.

[80] EPA does not determine the reuse of EPA-tracked sites. Reuse decisions for contaminated land, including EPA-tracked contaminated land, are made by individual property owners and in accordance with local and state land use regulations and any applicable cleanup program requirements.

[81] Estimate from Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., and Chen, D. 2008. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Urban Land Institute. Washington, D.C. Reflects only transportation related emissions from changes in land use patterns. Expected annual benefit through 2030.

[82] The 100% scenario represents 141 times the projected deployment of concentrating solar power in 2030. See Appendix for more detail. U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html.

[83] The 100% scenario could support 75% of the projected deployment of wind power in 2030. See Appendix for more detail. U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html.

Box 9: Summary of Total Technical Potential Scenarios

Land Revitalization [80]		Estimated GHG Emission Benefit
Reforest percentage of qualifying former mine lands for carbon sequestration:[84]	100%	4 MMTCO$_2$E/yr
	50%	2 MMTCO$_2$E/yr
	25%	1 MMTCO$_2$E/yr

* Most of the total technical potential scenarios presented in this table have been rounded to one significant figure. See Appendix A for more detail on these estimates.

These examples show the potential opportunity for EPA to reduce or avoid U.S. GHG emissions through encouraging improved cleanup, land restoration, and potential reuses at its tracked sites. EPA's land management activities could be replicated by other federal, state, and tribal agencies for even greater GHG emission reductions and avoidance.

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[84] Early research has shown that if biosolids or other soil amendments were used to enrich the soil with carbon, greater sequestration could occur.

SECTION 4
LOOKING FORWARD

EPA, along with its federal, regional, state, tribal, local, and other public and private partners, can help address the challenges of global climate change through materials and land management programs. As summarized by this document, there is a strong link between GHG emissions and the management of materials and land.

This document presents a systems-based framework through which to view U.S. GHG emissions. This approach complements the sector-based framework that focuses on the physical emissions source and demonstrates additional areas of GHG reductions that can be pursued. This systems-based approach demonstrates that up to 42% of U.S. emissions are linked to the way we manage and use materials, and that another 16-20% of U.S. emissions are linked to land management, along with the 13% of emissions that are offset by the carbon sink provided by U.S. land and vegetation. This analysis suggests that there are significant opportunities to reduce U.S. GHG emissions through modified materials and land management approaches.

To help illustrate some of the potential for GHG reduction and avoidance opportunities from materials and land management practices, this document also estimates the total technical potential of a variety of materials and land management approaches to reduce GHG emissions. The purpose of this document—to advance the understanding of the link between climate change and materials and land management—is an important step in achieving reductions in U.S. GHG emissions, and provides a platform from which to conduct further analysis and activities that complement current and future approaches to GHG emissions reductions.

Finally, this document is designed to be a model methodology that municipalities and states can replicate to identify their own options for shifting toward systems thinking and ways that materials and land management can impact GHG emissions. Future analysis by EPA may include the following:

- Conducting research and analysis to provide a greater number of and more detailed examples of materials and land management approaches that could be used to reduce GHG emissions. This could include providing options for localities, tribes, states, and others to maximize GHG emission reductions or select options that provide the best fit.
- Conducting research and analysis to provide information on the cost of implementing materials and land management approaches to reduce GHG emissions, to allow localities, tribes, states, and others to make better decisions regarding their return on investment and identify approaches that minimize cost.
- Providing analysis of climate change related policies being developed at the local, tribal, state, and federal levels and linking materials and land management approaches with the policy objectives.

Appendix

APPENDIX A

TECHNICAL SUPPORT FOR *OPPORTUNITIES TO REDUCE GREENHOUSE GAS EMISSIONS THROUGH MATERIALS AND LAND MANAGEMENT PRACTICES*

This appendix provides a description of the methodologies used to develop the systems-based pie chart of U.S. greenhouse gas (GHG) emissions showing materials and land management (Figures ES-1 and 2 through 5 in *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices*), as well as the methodologies supporting the total technical potential scenarios and the GHG emission reductions that could be achieved through materials and land management activities.

SECTION A-1

METHODOLOGY FOR CREATING THE SYSTEMS PIE CHARTS (FIGURES ES-1 AND 2 THROUGH 4)

As described in *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices* (the "main text"), Figure 1 was derived from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* ("the Inventory").[85] The Inventory comprehensively quantifies the country's primary anthropogenic sources and sinks of GHG emissions based on a common and consistent methodology that enables parties to the United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different emission sources and GHGs to climate change. In addition to reporting emissions by the standard categories set by the Intergovernmental Panel on Climate Change (IPCC) methodology, the Inventory presents emissions allocated to the economic sectors where they are emitted.[86] This is the basis of Figure 1, with 34% of emissions coming from Electric Power Industry sources, 28% from Transportation sources, 19% from Industrial sources, 8% from Agriculture sources, 6% from Commercial sources, and 5% from Residential sources.[87]

A collection of sources working together to fulfill a common need is termed a "system." To better understand and describe the connections between materials and land management and climate change, this paper presents a "systems-based" perspective. Rather than categorizing emissions according to the sector where they are emitted, emissions are categorized according to the need driving those emissions. There are many possible categorizations of GHG emissions by system, but the systems here are chosen to examine the role of materials management and land management. Figures 2 through 5 show the same 2006 GHG emissions as Figure 1, but reallocate the emissions by system, demonstrating how much of the U.S. GHG emissions are associated with materials and land management practices.

The systems perspective allows consideration of mitigation options that are not as evident in the sector-based view. By considering the practices that contribute to the emissions, not the physical emissions source, we can see where changes in practices upstream have the most potential to reduce

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[85] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html. This report relies on the Inventory data published in 2008; a more recent version, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, was published in 2009 and can be found at http://www.epa.gov/climatechange/emissions/usinventoryreport.html

[86] Ibid. Table 2-12.

[87] Emissions from U.S. territories are categorized as a separate sector, totaling 1% of total U.S. emissions; because these emissions are not allocated to economic sectors, they are not included here.

emissions downstream. The guiding principle behind the selection of systems presented in Figures 2 through 5 is that the emissions in each slice can be reduced by a collection of pollution prevention activities, including green design, industrial ecology, design for environment, sustainable consumption, materials management, and sustainable land management, which all seek to meet the needs addressed by current activities, but with lower resource demand and lower negative impact on the environment and human well-being. Each slice is the domain of a broad set of emissions reduction policies, and, in general, different policies address different slices. Figures 2 through 5 are designed to illustrate the importance of pollution prevention-oriented emissions reductions and of materials and land management in particular.

A summary of the sector- and systems-based allocation of 2006 U.S. GHG emissions is provided in Table 1, and measured in million metric tons of carbon dioxide equivalent (MMTCO$_2$E).

Table 1: U.S. GHG Emissions 2006, Sector-based Allocation and Systems-based Allocation

Sector-based Allocation	Emissions MMTCO$_2$E	% of Total**	Systems-based Allocation	Emissions MMTCO$_2$E	% of Total**
Electric Power Industry	2,378	34%	Provision of Goods	2,040	29%
Transportation	1,970	28%	Provision of Food	895	13%
Industry**	1,372	19%	Local Passenger Transport	1,019	15%
Agriculture	534	8%	Infrastructure	72	1%
Commercial	395	6%	Building HVAC and Lighting	1,719	25%
Residential	345	5%	Use of Appliances and Devices	581	8%
			Non-Local Passenger Transport**	666	9%
Total (excluding U.S. Territories)*	6,992	100%	**Total** (excluding U.S. Territories)*	6,992	100%
Land-based carbon sink	-884	-13%	Land-based carbon sink	-884	-13%
Net (excluding U.S. Territories)	6,108	87%	Net (excluding U.S. Territories)	6,108	87%
			Greenfield Development	≈314	≈4%

** Total excludes emissions from U.S. Territories of 62 MMTCO$_2$E (1%), which could not be disaggregated.*
*** % of Total rounded down to balance out rounding of other percentages, so that percentages sum to 100%.*

Table 2 provides a more detailed crosswalk showing the relationship between the sector- and systems-based allocations. In Table 2, each row corresponds to a sector. Moving across a row, the table shows the quantity of emissions allocated to each system from that sector. Moving down a column, or system, the table shows the contribution of emissions from each sector to that system.

Table 2: Detailed Crosswalk Between Sector-based and Systems-based Emissions (MMTCO$_2$E)

Sector/System*	Materials		Land Management		Other Emissions			*Sector Subtotal**
	Provision of Goods	Provision of Food	Local Passenger Transport	Infrastructure	Building HVAC and Lighting	Use of Appliances and Devices	Other Passenger Transport	
Electric Power Industry	572	112	16	8	1,244	416	9	*2,378*
Agriculture		533		0				*534*
Industry	912	106	122	55	73	24	78	*1,371*
Residential	14				235	96		*345*
Commercial	150	31		2	167	44		*395*
Transportation	392	112	882	6			578	*1,969*
*System Subtotal***	*2,040*	*895*	*1,019*	*72*	*1,719*	*581*	*666*	6,992
U.S. Territories								62
Total 2006 U.S. Anthropogenic GHG Emissions***								7,054
Land-based Carbon Sink								*-884*
Net 2006 U.S. Anthropogenic GHG Emissions								6,170
Development of Greenfields								≈314

** Sector Subtotals may not match those presented in Table 1 due to rounding.*
*** System Subtotals may not sum due to rounding.*
**** Total excludes emissions from U.S. Territories of 62 MMTCO$_2$E (1%), which could not be disaggregated.*

From the systems allocation we can see that materials management influences a large share of GHG emissions (42%). Land management influences a smaller share of emissions accounted for in the Inventory (16%), but also the substantial land-based carbon sink (equivalent to 13% of emissions). Though not currently accounted for in the Inventory, land management and especially land cleanup and revitalization practices, influence the bio-carbon emissions from clearing land for development (Greenfield Development). These emissions are estimated in this paper to be equivalent to approximately 4% of U.S. emissions.

Note that emissions that occur in other countries to produce or transport goods and services that are consumed in the U.S. are not captured in the U.S. Inventory. Therefore, Provision of Goods does not include emissions associated with foreign production of goods consumed in the U.S. or with international freight. Similarly, the Provision of Food does not include emissions from growing food internationally to be consumed in the U.S. or the freight emissions to bring it here. Neither do these systems subtract emissions from producing goods or food for export. However, many materials management activities have the effect of reducing emissions outside the U.S. by reducing emissions from the production of imported goods. If U.S. emissions were calculated based on consumption, from a life cycle perspective, emissions associated with materials management would be greater than reported here, due to net importation of GHG-intense goods.[88]

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[88] Weber, Christopher L. and H. Scott Matthews. 2007. *Emissions Embodied in U.S. International Trade*. Environmental. Science and Technology. Vol. 41, No. 14. July 15, 2007. pp. 4875-4881.

The remainder of Section A-1 describes the reasoning behind the allocation of emissions to each system, or slice of the pie charts in Figures 2 through 5, and the methodology used to estimate the emissions.

PROVISION OF GOODS

Table 3: Emissions Related to Provision of Goods

Emissions Source	*Sector*	Emissions ($MMTCO_2E$)
Industrial sector direct emissions*	*Industry*	793.4
Industrial sector electricity use*	*Electric Power Industry*	563.0
Freight*	*Transportation*	391.6
Landfill methane**	*Commercial*	123.3
Substitution of ozone-depleting substances	*Commercial, Residential*	35.3
Industrial wastewater treatment	*Commercial*	4.3
Residential soil fertilization	*Residential*	1.5
Upstream industrial sector fossil fuel combustion	*Industry*	127.7
Total Emissions from Provision of Goods		2,040

** Except emissions related to food and beverage processing and infrastructure construction.*
*** Except emissions related to infrastructure construction.*

GHG emissions associated with extraction, production, transportation, and disposal of materials and non-food goods were estimated at approximately 2,040 $MMTCO_2E$ in 2006, or 29% of total emissions. This includes direct emissions from the industrial sector, emissions from electricity use by the industrial sector, emissions from freight transport, landfill methane, the substitution of ozone-depleting substances, industrial wastewater treatment, residential fertilization and emissions from extraction and processing of fossil fuels used to produce and transport goods. The total excludes some of these emissions included in other slices.

The emissions associated with the Provision of Goods can be reduced through policies that promote improved materials management. While the emissions come from disparate sources, like mining operations, manufacturing plants, and freight trucks, many materials management strategies address all these sources together. For instance, a program that extends the life of a product will reduce extraction of raw materials and emissions from manufacturing, transport, and disposal of the replaced product.

This slice represents the emissions from all stages of material flow except for product use. Use phases for non-industrial products are addressed in other slices, for example, the use phase of appliances are included in Use of Appliances and Devices. The reasoning for separating the use phase impacts of appliances, devices, and buildings into other slices is explained in Section 2 of the main text.

Some products, notably food, are addressed entirely in other slices. The life cycle impacts of constructing infrastructure are excluded from this slice because they are included in the Infrastructure slice.

It is arguable that energy use by retail and commercial establishments that sell goods and services, as well as emissions from personal transportation to obtain goods and services, could be included in the Provision of Goods estimate; however, it seems likely that these emissions would be addressed by more general policies related to building energy use and land use planning rather than policies that address the provision of goods, so they were not included here.

Table 3 details the contribution of the various sources to the emissions total for the Provision of Goods. Direct emissions from the industrial sector include fossil fuel combustion and emissions from industrial processes. The total is taken from Table 2-12 of the Inventory and then emissions associated with food and beverage processing and with constructing infrastructure (see following sections) are subtracted. Industrial sector electricity use is taken from Table 2-14 of the Inventory. Industrial wastewater treatment emissions include only emissions associated with pulp and paper manufacturing and ethanol manufacturing, as calculated by methods presented in the Inventory (the remaining 87% of wastewater treatment emissions are attributed to the food system). Emissions from landfills, substitution of ozone-depleting substances, and residential soil fertilization come from Table 2-12 of the Inventory.

Freight emissions are estimated by apportioning the transportation-related emissions from Table 2-15 of the Inventory using mode-specific energy consumption data from the *Transportation Energy Data Book.*[89] The fraction of emissions in each mode associated with food products is then subtracted (see next section). Included in the freight total are emissions from Class I freight railroads, water-borne freight vessels, pipelines, and medium- and heavy-duty on-road trucks. Rail freight emissions were based on the proportion of rail energy consumption associated with Class I freight railroads (87%) with the rest attributed to passenger transportation (see Local Passenger Transport and Other Passenger Transport). Water-borne commerce was estimated by using the proportion of energy consumption associated with domestic water-borne commerce (55%) with the balance attributed to recreational boating (see Other Passenger Transport). Pipeline-related emissions and on-road medium- and heavy-duty trucks are counted in their entirety.

This calculation omits air freight emissions, since adequate data were not readily available to separate freight and passenger emissions. Also, any freight-related emissions from light trucks are not counted, while some of the emissions due to heavy trucks may include on-road trucks not used for freight. In general, this estimate is intended to indicate relative magnitude rather than precise emissions.

As mentioned above, industrial emissions from fossil fuel extraction and processing are subtracted from the industrial emissions total and most are not included in Provision of Goods. Fuel extraction and processing emissions are calculated using the EPA report *Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States.*[90] The emissions are subtracted from the Inventory's "Industry" and Electric Power Industry" economic sectors, and allocated to their respective systems based on the fuels or electricity used by those systems. Emissions associated with petroleum systems and natural gas systems are taken from the Inventory. The emissions from industrial fossil fuel combustion and industrial electricity use are based on proportions established by data from the Sector

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[89] Davis, S. and S. Diegel. 2008. *Transportation Energy Data Book: Edition 27*. Oak Ridge National Laboratory. Available at: http://cta.ornl.gov/data/index.shtml

[90] U.S. EPA. Sector Strategies Program. 2008. *Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States*. (Working Draft). Table 12-1. Available at: http://www.epa.gov/ispd/pdf/greenhouse-report.pdf

Strategies report.[91,92] These proportions represent the value of petroleum and natural gas emissions from industrial fossil fuel combustion and industrial electricity use relative to total industrial sector emissions. The resulting percentages are then applied to the Inventory data for these source categories.

The emissions from petroleum extraction and refining are allocated according to the relative value of each system's transportation emissions to total transportation emissions. The majority of these emissions are allocated to the Local Transportation and Other Transportation system slices. A fraction of these emissions are also allocated to the Provision of Good and Provision of Food slices based on the proportion of transportation emissions allocated to freight. An additional portion is allocated to Provision of Goods according to the proportion of petroleum used as a chemical feedstock (e.g. for plastics).

The emissions from natural gas extraction and distribution are apportioned in a similar fashion. The majority of these upstream emissions are associated with building energy use; therefore, most of the emissions are allocated to the Building HVAC and Lighting slice, as well as the Use of Appliances and Devices slice. However, a fraction of these emissions are attributed to the Provision of Goods slice to account for industrial use of natural gas.

PROVISION OF FOOD

Table 4: Emissions Related to Provision of Food

Source	*Sector*	Emissions ($MMTCO_2E$)
Agriculture sector direct emissions*	*Agriculture*	533.3
Food processing sector energy use	*Electric Power and Industry*	113.1
Food-related freight	*Transportation*	112.3
Agriculture sector electricity use	*Electric Power*	62.3
Wastewater treatment**	*Commercial*	27.7
HFC emissions from refrigeration and refrigerated transport	*Industry*	16.6
Composting	*Commercial*	3.3
Upstream industrial sector fossil fuel combustion	*Industry*	26.1
Total Emissions from Provision of Food		895

** Except emissions from infrastructure construction.*

*** Except from pulp and paper manufacturing and ethanol production.*

GHG emissions associated with the production, processing, distribution, and disposal of food (i.e., Provision of Food) were approximately 895 $MMTCO_2E$ in 2006, or 13% of U.S. emissions. This includes direct emissions from agricultural sources, food processing energy use, transportation of food-related products, agriculture sector electricity use, treatment of municipal and food processing wastewater,

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[91] Ibid.

[92] The data in this report is taken from U.S. EPA. 2007. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.* Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html

leaks of hydrofluorocarbons (HFCs) from refrigeration equipment, composting, and fossil fuel extraction and processing.

It is arguable that energy use by commercial establishments such as supermarkets and restaurants could be included in this slice; however, it seems likely that these emissions would be addressed by more general policies related to building energy use and land use rather than policies that address agriculture and food-processing emissions, so they were not included here.

Prevention-oriented or materials management approaches to reduce emissions from the food system include source reduction and effective management of food wastes and agricultural residues—for example, composting, waste-to-energy, and activities that shift demand from higher-impact foods or production inputs to lower impact foods or inputs.

Table 4 shows a breakdown of emissions in the Provision of Food slice. Emissions from agricultural sources and agricultural electricity use are taken from Table 2-14 of the Inventory. These sources of emissions include fossil fuel combustion, enteric fermentation, manure management, rice cultivation, field burning of agricultural residues, and agricultural soil management. A small portion of emissions (<0.1%) are subtracted and attributed to infrastructure construction (see Infrastructure section). Composting emissions are also provided by the Inventory.

Energy-related emissions from food processing were calculated using energy consumption reported in the Energy Information Administration (EIA) *2002 Manufacturing Energy Consumption Survey*[93] for the “Food” and “Beverages” industry groups. Energy consumption was multiplied by fuel-specific carbon contents and converted to carbon dioxide (CO_2) emissions.[94,95] For “other” fuels, the emissions factor for “Petroleum – Miscellaneous Products” was applied. All fuels were summed to provide 2002 emissions. This value was then scaled up to 2006 using the ratio of the 2006 gross output value in the food and beverage industry to the 2002 value, adjusted for inflation.[96,97]

HFC emissions related to the Provision of Food are estimated by taking a portion of total HFC emissions from refrigeration and air conditioning. The total is provided by the Inventory and the distribution among various end-uses is given in the EPA report, *Global Mitigation of Non-CO_2 Greenhouse Gases.*[98] Among these end uses, “refrigerated transport” (14% of total emissions) and “cold storage” (1.2%) are attributed to the food system. The “industrial process” end use (4.6%) likely includes applications both in food and non-food sectors. Since further detail was not available, half of the emissions from industrial processes are assumed to be related to food. In all, 17.5% of HFC emissions are from refrigeration attributed to the Provision of Food.

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[93] U.S. Department of Energy, Energy Information Administration. 2005. *Manufacturing Energy Consumption Survey, 2002, (MECS).* Available at: http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/pdf/table3.2_02.pdf

[94] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*. Tables A-29 and A-30. Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html

[95] U.S. Department of Energy, Energy Information Agency. 2007. *Summary Statistics for the United States*. Available at: http://www.eia.doe.gov/cneaf/electricity/epa/epates.html

[96] Howells III, T.F., K.B. Barefoot, and B.M. Lindberg. 2006. “Annual Industry Accounts: Revised Estimates for 2003-2005.” *Survey of Current Business,* 86:12. U.S. Department of Commerce, Bureau of Economic Analysis. Available at: http://www.bea.gov/scb/pdf/2006/12december/1206_indyaccts.pdf

[97] Kim. S. Vincent, D.A., Jacobson, A.M., and Lyndaker A.S. 2008. “Annual Industry Accounts: Revised Estimates for 2005-2007.” *Survey of Current Business.* U.S. Department of Commerce, Bureau of Economic Analysis.

[98] U.S. EPA. 2006. *Global Mitigation of Non-CO_2 Greenhouse Gases.* Available at: http://www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf

Transportation of food-related products was estimated using data from the 2002 Commodity Flow Survey.[99] This study provides freight totals by ton-miles and freight mode for major commodity groups. First, all food- and beverage-related product groups were identified and ton-mileages were summed by mode for these product groups. For multi-modal freight, the total is divided evenly between the mode (e.g., ton-mileage listed under "truck and rail" is divided evenly between the truck category and the rail category). Using this method, it was estimated that food-related products accounted for 23% of truck freight, 19% of rail freight, and 35% of water-borne freight on a ton-mileage basis. Emissions were then estimated by multiplying these percentages by the freight emissions associated with each mode, as determined in the Provision of Goods section. Freight listed as "other/unknown" is assumed equivalent to the truck category and freight listed as "other multiple modes" was evenly divided among all modes. Emissions associated with air freight were omitted due to lack of data on total emissions from air freight.

Wastewater treatment-related emissions are taken from the Inventory, subtracting emissions associated with non-food industrial products as discussed in the previous section. The remaining emissions (87%) include emissions from municipal wastewater treatment and from the processing of meat, poultry, fruit, vegetables and juices. The upstream industrial fossil fuel combustion emissions were determined using the same methodology as stated in the previous section.

LOCAL PASSENGER TRANSPORT

Table 5: Emissions Related to Local Passenger Transport

Source	*Sector*	Emissions ($MMTCO_2E$)
Local trips by cars, light trucks, and motorcycles*	*Transportation*	865.8
Urban rail emissions	*Transportation*	5.4
Local bus emissions	*Transportation*	10.6
Electricity use	*Electric Power*	1.0
Upstream industrial sector fossil fuel combustion	*Industry*	136.1
Total Emissions from Local Passenger Transport		1,019

** Local is defined as trips shorter than 50 miles.*

GHG emissions associated with Local Passenger Transport were approximately 1,019 $MMTCO_2E$, or 15% of total anthropogenic emissions in 2006. This is dominated by fuel combustion by cars and light trucks making short trips, but includes emissions from buses, light rail, electricity use, and fossil fuel extraction and processing. Local Passenger Transport is presented separately from Other Passenger Transport with the expectation that each is subject to a different set of prevention-oriented mitigation options. Local Passenger Transport emissions can be reduced through land management practices such as infill development and effective urban planning, as well as through enhancing public transit. These approaches complement sector-wide mitigation strategies, such as biofuel substitution or improved vehicle fuel economy because they reduce the number of vehicle miles traveled, reducing emissions from vehicle manufacturing, road maintenance, and non-GHG pollution as co-benefits. These strategies can work in concert with sector-wide strategies to reduce overall transportation emissions.

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[99] U.S. Department of Transportation, Bureau of Transportation Statistics. 2004. *Commodity Flow Survey, 2002.* Available at: http://www.bts.gov/publications/commodity_flow_survey/

Total GHG emissions from each transportation mode are taken from Table 2-15 of the Inventory. Emissions from on-road passenger vehicles, including passenger cars, light-duty trucks, and motorcycles, were split between local and long-distance ("other") according to the ratio of vehicle miles traveled (VMT) for each type of trip. Based on the *National Household Transportation Survey,*[100] roughly 30% of VMT in personal vehicles are on long-distance trips (defined as trips greater than 50 miles) and the other 70% are for local trips. The most recent data available were for 2001, and that ratio was assumed to hold constant for 2006.

Emissions from buses were apportioned using the relative energy consumption of transit buses and school buses (both considered to be local) compared with inter-city buses (non-local). The most recent year that data for all three were available was 2000.[101] Using this method, it was assumed that 85% of bus emissions were local and 15% of bus emissions were long-distance. Rail emissions were split in a similar way, using data from Davis and Diegel.[102] Commuter rail and transit accounted for 11% of rail-related energy consumption. Another 2% was used by Amtrak and assumed to be long-distance. The remaining rail emissions are allocated to freight (see Provision of Goods). The upstream industrial fossil fuel combustion emissions were determined using the same methodology as stated in the Provision of Goods section.

This method provides a rough estimate for the major categories of transportation emissions. It neglects some of the different fuel needs and emissions patterns of different types of transportation. For instance, rail transit is likely to use electricity due to air quality concerns in urban areas, while freight rail is more likely to use diesel. Passenger cars, meanwhile, are likely to get better mileage on long-distance highway trips than in local travel with frequent stops and starts. These effects were not accounted for.

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[100] U.S. Department of Transportation, Bureau of Transportation Statistics. 2003. *Highlights of the 2001 National Household Travel Survey.* Available at: http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/

[101] Davis, S. and S. Diegel. 2006. *Transportation Energy Data Book: Edition 25.* Oak Ridge National Laboratory. Available at: http://cta.ornl.gov/data/index.shtml

[102] Davis, S. and S. Diegel. 2008. *Transportation Energy Data Book: Edition 27*. Oak Ridge National Laboratory. Available at: http://cta.ornl.gov/data/index.shtml

OTHER PASSENGER TRANSPORT

Table 6: Emissions Related to Other Passenger Transport*

Source	*Sector*	Emissions ($MMTCO_2E$)
Long-distance trips by cars, light trucks, and motorcycles*	*Transportation*	371.1
Commercial aircraft	*Transportation*	143.6
Other aircraft (including military)**	*Transportation*	28.8
Recreational boating	*Transportation*	21.5
Inter-city bus emissions	*Transportation*	1.9
Lubricants	*Transportation*	9.9
Inter-city passenger rail (Amtrak)	*Transportation*	1.1
Other transportation emissions	*Transportation*	0.2
Fossil fuel extraction and processing	*Industry*	87.8
Total Emissions from Other Passenger Transport		666

* *Long-distance is defined as trips shorter than 50 miles.*

** *Includes small non-passenger contributions from military freight, commercial air freight and lubricants (which could not be disaggregated).*

This section describes transportation emissions not included in the Provision of Goods, Provision of Food or Local Passenger Transport slices. Long-distance passenger travel accounted for 90% of these remaining emissions, including emissions from aircraft, inter-city rail, inter-city buses, cars and light trucks making long-distance trips, and fossil fuel extraction and processing. Miscellaneous emissions, primarily from military aircraft and recreational vehicles, comprised the other 10% of this category. In all, non-local passenger transportation accounted for 666 $MMTCO_2E$, or 9% of U.S. GHG emissions in 2006.[103] Land management policies have less of an effect on non-local transportation, which is why these emissions are presented separately. Prevention-oriented policies to reduce inter-city passenger transportation include activities which shift travel to lower-impact modes of travel and promote more efficient loading or movement within modes.

As in the previous section, emissions in this section are calculated by taking the mode-specific total GHG emissions from Table 2-15 of the Inventory and apportioning them using various transportation end-use data. Emissions from cars, light-duty trucks, and motorcycles were split between local and long-distance according to the ratio of VMT for each type of trip. Based on the *National Household Transportation Survey,*[104] roughly 30% of VMT in personal vehicles are on long-distance trips (defined as trips greater than 50 miles) and so 30% of passenger vehicle emissions are included here. According to the *Transportation Energy Data Book,*[105] 55% of energy used in boating is for water born-commerce. The remaining 45% is assumed to be associated with recreational boating and this fraction is applied to the total emissions from boating and included here. The fraction of energy used by rail that is apportioned to Amtrak (2%) is assumed to be long-distance passenger travel and counted here. Aircraft emissions, which include commercial aircraft, military aircraft, and general aviation, as well as emissions from lubricants, are included in their entirety. This section also includes a small contribution

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[103] Percent of total rounded down from 10% to 9%, so that percentages sum to 100% in the systems-based pie charts.

[104] U.S. Department of Transportation, Bureau of Transportation Statistics. 2003. *Highlights of the 2001 National Household Travel Survey.* Available at: http://www.bts.gov/publications/highlights_of_the_2001_national_household_travel_survey/

[105] Davis, S. and S. Diegel. 2008. *Transportation Energy Data Book: Edition 27.* Oak Ridge National Laboratory. Available at: http://cta.ornl.gov/data/index.shtml

of other transportation sources, such as recreational vehicles and some off-road equipment. The upstream industrial fossil fuel combustion emissions were determined using the same methodology as stated in the Provision of Goods section.

INFRASTRUCTURE

Table 7: Emissions Related to Infrastructure System

Source	*Sector*	Emissions ($MMTCO_2E$)
Highway, street, bridge, and tunnel construction direct emissions	*Electric Power, Industry, Transportation, Agriculture, Commercial*	32.6
Highway, street, bridge and tunnel construction indirect, life cycle emissions	*Electric Power, Industry, Transportation, Agriculture, Commercial*	24.3
Water, sewer, and pipeline construction direct emissions	*Electric Power, Industry, Transportation, Agriculture, Commercial*	6.7
Water, sewer, and pipeline construction indirect, life cycle emissions	*Electric Power, Industry, Transportation, Agriculture, Commercial*	8.9
Total Emissions from Infrastructure System		72

The construction of infrastructure (roads and water systems) generated roughly 72 $MMTCO_2E$, or 1% of U.S. GHG emissions in 2006. This includes both direct emissions from construction equipment and indirect emissions from, for example, the production of concrete and the manufacturing of that construction equipment. Land management directly affects how and where we develop land, and therefore, how much infrastructure (e.g., highways, roads, sewers) is needed to link developed areas. Prevention-oriented approaches to reducing emissions from infrastructure consumption include the cleanup, revitalization, and reuse of previously-used land; and more compact development patterns.

This analysis to estimate the GHG emissions associated with infrastructure construction and maintenance is based on the Economic Input-Output Life Cycle Assessment (EIO-LCA) Model developed by the Carnegie Mellon Green Design Institute.[106,107] The model consists of a web-based database analysis that produces an estimate of the impacts from producing a certain dollar amount of 500 commodities or services in the U.S. Impacts reported by the model for each sector include conventional air pollutants, GHGs, energy, and toxic releases.[108]

The model captures all the various manufacturing, transportation, mining, and related requirements to produce a product or service, and traces out the resulting economic transactions, resource requirements, and environmental emissions. The life cycle assessment is based on an economic input-output model of the U.S. economy developed by the Department of Commerce combined with publicly available data and linear algebraic calculation methods.[109]

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[106] Hendrickson, C.T., L.B. Lave, and H.S. Matthews. 2005. *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach.* Resources for the Future Press.

[107] Carnegie Mellon University Green Design Institute. 2008. *Economic Input-Output Life Cycle Assessment (EIO-LCA) model.* Available at: http://www.eiolca.net/

[108] Carnegie Mellon University Green Design Institute. 2008. *Economic Input-Output Life Cycle Assessment (EIO-LCA) model.* Available at: http://www.eiolca.net/cgi-bin/dft/use.pl

[109] For a description of the limitations of using such models, refer to: http://www.eiolca.net/Method/Limitations.html

The model includes the entire supply chain of requirements. For example, the effects of producing a $20,000 car would not only include the impact of the final assembly, but also the impact of mining metals, making electronic parts, forming windows, and creating the other necessary components. Since the impact model is linear, the effects of a $20,000 car purchase, for example, would be double that of a $10,000 motor vehicle. Also, the data are only for production, so the impacts associated with end-use (for example, the impacts of gasoline use and maintenance for the $20,000 car) would need to be evaluated separately with the EIO-LCA model.

The data in the EIO-LCA Model are developed from a variety of public datasets and assembled for various commodity sectors. For the most part, the data are self-reported and subject to measurement error and reporting requirements gaps. Table 8 presents selected EIO-LCA data sources.

Table 8: EIO-LCA Model Data Sources

Data Element	Data Source, Calculation, and/or Information
Input/Output (IO) Matrix	1997 model is based upon the Department of Commerce's 491 sector industrial IO model of the U.S. economy.
Economic Impacts	Computed from the IO matrix and the user input change in final demand. Economic impacts are reported in 1997 dollars (millions).
Electricity Use	Includes manufacturing and mining sectors developed from the 1997 Census of Manufacturers. Service sector electricity use is estimated using the detailed IO work files and average electricity prices for these sectors.
Energy Use	Calculated by converting fuel use per sector and 31% of electricity use into terajoules (31% is the amount of electricity produced in 1997 from non-fossil fuel sources).[110]
Fertilizer Use	Calculated from commodity purchases (contained in the IO work files) and average 1997 prices.
GHG Emissions	Data were estimated using heating values and emission factors, as well as sectoral fuel use data of the updated 1997 industry benchmark EIO-LCA model. The emission factors are taken from IPCC guidelines. Global warming potential (GWP) was estimated using the IPCC Third Assessment Report: Climate Change 2001.[111]

The U.S. Department of Commerce 1997 Industry Benchmark EIO-LCA Model is used to estimate emissions resulting from construction of infrastructure including highway, street, bridge, and tunnel construction, as well as water, sewer, and pipeline construction. The model is used to calculate pure emission outputs based on the total industry outputs in millions of dollars. The total industrial output used for highway, street, bridge, and tunnel construction is $43,401 million (in 1997 dollars).[112] The total output used for water, sewer, and pipeline construction is $17,207 million (in 1997 dollars).[113] Tables 9 and 10 present the top 20 emission sources of the hundreds that were reported by the EIO-LCA Model for infrastructure. The totals of each table represent the total emissions for all sources, including those not shown. All of these emissions have been allocated to the Infrastructure slice of the pie chart.

In order to complete the crosswalk presented in Table 2, it was necessary to identify which economic sectors the infrastructure emissions were originally associated with, so they could be subtracted out

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[110] Fuel, electricity, and energy estimates are normalized based on additional data from the U.S. Census Bureau, data from the Manufacturing Energy Consumption Survey (MECS) Consumption of Energy, the U.S. Department of Energy Transportation Energy Data Book, and U.S. EPA data conversion factors. For more information, refer to: http://www.eiolca.net/remakingenergy.pdf

[111] Cicas, Gyorgyi, et al. 2006. *The 1997 Benchmark Version of the Economic Input-Output Life Cycle Assessment (EIO_LCA) Model*. Green Design Institute, Carnegie Mellon University. Available at: http://www.eiolca.net/data/full-document-11-1-06.pdf

[112] Carnegie Mellon University Green Design Institute. 2008 *Economic Input-Output Life Cycle Assessment (EIO-LCA) model.* Available at: http://www.eiolca.net/sectors1997.html

[113] Ibid.

and reallocated to the Infrastructure slice. To identify the sectors, the EIO-LCA model's hierarchy of North American Industry Classification System (NAICS) codes were reviewed and each emission source was assigned to a sector based on Bureau of Economic Analysis guidance. For example, "Stone mining and quarrying" was assigned to the "Industry" economic sector in the Inventory and "Waste management and remediation services" was assigned to "Commercial." Table 11 shows the final proportion of infrastructure emissions that was extracted from each economic sector and reallocated to the Infrastructure slice in the systems pie chart (Figures ES-1 and 2 through 5).

Table 9: Emissions Related to Highway, Street, Bridge and Tunnel Construction
(Top 20 sources; Industry output $43,401 million)

Economic Sector	Emission Source	GWP Emissions (MTCO$_2$E)
Industry	Highway, street, bridge, and tunnel construction	32,633,776
Electricity	Power generation and supply	5,999,036
Transportation	Truck transportation	2,868,386
Industry	Cement manufacturing	2,827,754
Industry	Oil and gas extraction	1,693,483
Industry	Petroleum refineries	1,556,906
Commercial	Waste management and remediation services	864,638
Industry	Iron and steel mills	617,476
Transportation	Pipeline transportation	616,609
Industry	Asphalt paving mixture and block manufacturing	353,671
Transportation	Air transportation	332,358
Industry	Stone mining and quarrying	316,474
Industry	Nitrogenous fertilizer manufacturing	302,009
Industry	Sand, gravel, clay, and refractory mining	300,800
Industry	Coal mining	256,260
Industry	Lime manufacturing	250,575
Electricity	State and local government electric utilities	248,212
Industry	Ready-mix concrete manufacturing	246,842
Transportation	Rail transportation	243,367
Industry	Asphalt shingle and coating materials manufacturing	236,910
	Total for all Sectors (including those not shown)	56,900,000

** May not sum to total due to independent rounding.*

Table 10: Emissions Related to Water, Sewer, and Pipeline Construction
(Top 20 sources; Industry output $17,207 million)

Sector	Source	GWP Emissions (MTCO$_2$E)
Industry	Water, sewer, and pipeline construction	6,652,123
Electricity	Power generation and supply	2,138,640
Industry	Cement manufacturing	986,204
Transportation	Truck transportation	958,747
Industry	Iron and steel mills	952,098
Industry	Oil and gas extraction	361,473
Commercial	Waste management and remediation services	344,837
Industry	Petroleum refineries	314,915
Transportation	Air transportation	161,143
Industry	Coal mining	154,147
Transportation	Pipeline transportation	145,702
Industry	Lime manufacturing	121,490
Industry	Other concrete product manufacturing	105,855
Industry	Nitrogenous fertilizer manufacturing	94,104
Electricity	State and local government electric utilities	91,051

Table 10: Emissions Related to Water, Sewer, and Pipeline Construction
(Top 20 sources; Industry output $17,207 million)

Sector	Source	GWP Emissions (MTCO$_2$E)
Industry	Petroleum lubricating oil and grease manufacturing	84,448
Electricity	Wholesale trade	82,518
Industry	Industrial gas manufacturing	81,331
Industry	Primary aluminum production	81,173
Transportation	Rail transportation	77,328
	Total for all Sectors (including those not shown)	15,500,000

** May not sum to total due to independent rounding.*

Table 11: Percentage of Emissions from Highway, Street, Bridge and Tunnel Construction Extracted from Economic Sectors

Economic Sector	Proportion of Highway, Street, Bridge and Tunnel Construction Emissions	Proportion of Water, Sewer, and Pipeline Construction Emissions
Electricity	11%	14%
Industry	78%	71%
Transportation	8%	10%
Agriculture	<1%	<1%
Commercial	3%	4%
Residential	0%	0%
Total for all Sectors*	100%	100%

** May not sum to total due to independent rounding.*

LAND-BASED CARBON SINK

Table 12: Emissions Offset by Land-based Carbon Sink

Sink Source	Emissions (MMTCO$_2$E)
Land-based Carbon Sink (carbon stock changes in land use, land-use change, and forestry)	-884

Carbon dioxide (CO_2) is absorbed by land and vegetation through the process of photosynthesis. The net emissions are negative (sequestration) and substantial, offsetting approximately 884 MMTCO$_2$E, or approximately 13% of total emissions in 2006.[114] The carbon sequestration and storage provided by land can be preserved though sustainable land management practices, and can be enhanced by restoration of land, such as reforestation of contaminated land.

The emissions estimate for the land-based carbon sink is given by the Inventory. Specifically, Chapter 7, *Land Use, Land-Use Change, and Forestry*, provides an assessment of the net GHG flux resulting from the uses and changes in land types and forests in the U.S., including net emissions from forestland remaining forestland, cropland remaining cropland, land converted to cropland, grassland remaining grassland, land converted to grassland, settlements remaining settlements, landfill yard trimmings, and

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[114] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2006*. Chapter 7. Land Use, Land-Use Change, and Forestry. Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html

food scraps. It should be noted that while mature ecosystems have a carbon flux of essentially zero, much of the forest land in the U.S. is growing or re-growing, which contributes to the net sink.

GREENFIELD DEVELOPMENT

Table 13: Emissions Related to Greenfield Development System

Emissions Source	Emissions ($MMTCO_2E$)
Lost soil carbon	202
Lost biomass carbon	81
Lost dead organic matter carbon	31
Total Emissions from Greenfield Development System	314

Greenfield development (that is, conversion of natural land or farmland to a residential, commercial, or industrial use) results in GHG emissions from the decay and release of organic carbon to the atmosphere ("bio-carbon emissions"). Bio-carbon can be released from soil, plants, and dead organic matter (DOM), such as leaf litter. Greenfield development may also cause net emissions by foregoing future carbon absorption if the land developed is an active sink, such as a growing forest. This effect, of foregone future absorption, is not accounted for here.

As with the land-based carbon sink discussed in the previous section, policies that promote land revitalization, land reuse, and denser development in place of new land development will reduce bio-carbon emissions from greenfield development. The estimate in this section is presented partly to show the scale of potential emissions reductions available through land reuse.

Although the Inventory includes a chapter on Land Use, Land-Use Change, and Forestry (see previous section), emissions from greenfield development are not currently included due to lack of accurate data. We provide a rough estimate here since emissions from greenfield development are critically linked to land revitalization and reuse and this link is relatively unexplored. These emissions fall mostly or completely outside the official inventory, and so can not be integrated with the systems allocation in a consistent way. The total is estimated at 314 $MMTCO_2E$, or the equivalent of approximately 4% of U.S. emissions. This estimate is highly uncertain compared with other emissions estimates in the Inventory.

The analyses used to calculate soil, biomass, and DOM carbon loss are based on the methodologies and recommendations made by the IPCC in "IPCC Guidelines for National Greenhouse Gas Inventories."[115] The GHG inventory produced by U.S. EPA in 2008 used the 1996 IPCC guidelines as a basis, but supplemented the results using the 2006 IPCC guidelines.[116] The IPCC 2006 guidelines identify three basic carbon pools that can be affected by new land development: carbon in soil, carbon in biomass, and carbon in DOM.

To the extent possible, the analysis follows a Tier 1 approach as proposed by the IPCC 2006 guidelines. A Tier 1 approach is designed to be the simplest to use (the more sophisticated Tier 2 and Tier 3

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[115] Intergovernmental Panel on Climate Change. 2006. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

[116] U.S. EPA. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.* Available at: http://www.epa.gov/climatechange/emissions/usgginv_archive.html

approaches require more extensive and localized data than were available for this analysis). It makes use of default parameter values that are provided in the guidance document. Although some country-specific activity data are needed, much of the remaining information is gathered from global sources about emissions and stock change factors. Please note that there are specific instances where this analysis deviates from a Tier 1 approach because the IPCC-recommended country or region specific information was not available. Those instances are noted.

The change in soil as a consequence of new land development is estimated by:

$$\Delta C_{SOIL} = \frac{(Cs_n - Cs_o) \cdot A_{ON}}{T_{ON}}$$

- ΔC_{SOIL} = Annual change in carbon stocks in soil, tonnes C yr^{-1}
- Cs_o = Soil carbon stock, under old land-use category, tonnes C yr^{-1}
- Cs_n = Soil carbon stock, under new land-use category, tonnes C yr^{-1}
- A_{on} = Area undergoing conversion from old to new land-use category, ha
- T_{on} = Time period of transition, default is 1 year for carbon losses

Although this equation is similar to the equation used to estimate carbon losses in DOM (see below), it is not in accordance with the 2006 IPCC Guidelines. The guidelines recommend a greater degree of disaggregation of land-use data by climate and soil type. The equation above represents a simplification of the variability of carbon contents in soil that exists on regional and national scales. The soil carbon stock for the old land use category (Cs_o) was based on information for different ecosystem types presented in the 2000 IPCC report on Land Use, Land-use Change, and Forestry.[117] The soil carbon stock for the new land use category of settlements (Cs_n) was based on a fraction of Cs_o. For forestland and grassland, the fraction was 0.5 and for cropland, the fraction was 0.8. Guo and Gifford (2002) observed that land use changes of forestland to cropland and pastureland to cropland resulted in soil carbon decreases of 42% and 59%, respectively.[118] The estimate for this project assumes that the conversion of forestland or grassland to urban land is equivalent to a conversion to cropland (both remove existing vegetation and cause significant soil disturbance); therefore, Guo and Gifford's work supports this effort's estimation of a 50% loss associated with this conversion. It is estimated that soils under forests or grasslands will lose approximately 50% of the original organic carbon when the land is converted to developed land. These losses are a consequence of both the removal of surface soils (to provide suitable building foundation) and natural oxidation when the soil is graded following removal of the vegetative cover. Losses from croplands are only expected to be 20% because these soils already undergo periodic tillage and the majority of natural oxidation will already have occurred. A literature review for this project did not identify other studies comparable to Guo and Gifford (2002) that estimated soil carbon losses associated with converting cropland to urban land. Therefore, the 20% soil carbon loss estimate for development of cropland into urban land is based on best professional judgment.

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[117] Intergovernmental Panel on Climate Change. 2000. *Land Use, Land-Use Change and Forestry*. Available at: http://www.grida.no/Climate/ipcc/land_use/index.htm

[118] Guo, L.B. and Gifford, R.M. 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biology (8):4: 345–360.

The change in biomass carbon stocks as a consequence of new land development is estimated using the following equations:

$$\varDelta C_B = \varDelta C_G + \varDelta C_{CONVERSION} - \varDelta C_L$$

$$\varDelta C_{CONVERSION} = \sum_i \left\{ \left(B_{AFTER_i} - B_{BEFORE_i} \right) \varDelta A_{on} \right\} CF$$

- ΔC_B = Annual change in carbon stocks in biomass on land converted to another land-use category, tonnes C yr^{-1}
- ΔC_G = Annual increase in carbon stocks in biomass due to growth on land converted to another land use category, tonnes C yr^{-1}
- $\Delta C_{CONVERSION}$ = Initial change in carbon stocks in biomass on land converted to another land-use category, tonnes C yr^{-1}
- ΔC_L = Annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood and disturbances on land converted to another land use category, tonnes C yr^{-1}
- B_{AFTER} = Biomass stock on land type *i* immediately after conversion, tonnes dry matter ha^{-}
- B_{BEFORE} = Biomass stock on land type *i* immediately before conversion, tonnes dry matter ha^{-}
- ΔA_{ON} = Area of land use *i* converted to another land-use category, ha yr^{-}
- CF = Carbon fraction of dry matter (tonnes C) · (tonnes dry matter)$^{-1}$; default is 0.5

Key assumptions based on the 2006 IPCC Guidelines are that for a Tier 1 approach, $\Delta C_G = \Delta C_L$, and the net effect on ΔC_B is zero when land is converted to settlements. Therefore it is not necessary to develop estimates for these components. Also, B_{AFTER} is assumed to be zero (development removes all biomass from the converted land). Although B_{AFTER} is likely a positive value in practice, it was beyond the scope of this analysis to estimate a non-zero value for B_{AFTER}.

B_{BEFORE} is based on default values provided in the 2006 IPCC guidelines. The estimates for ΔA_{ON} are based on the results provided in the 2003 National Resource Inventory prepared by the Natural Resources Conservation Service.[119] This inventory provided estimates for amounts of rural land converted into developed land (settlements) between 1997 and 2001. For the purposes of this initial analysis, we used the average amount of annual conversion over the time period studied and assumed the same rate of conversion for 2006: 2.2 million acres per year.[120] The rural lands identified in the resource inventory were classified into forest, crop, pasture, range, and other. For this analysis, pasture and range land were combined into grassland. Other land is defined as farmsteads, farm structures, windbreaks, barren land, and marshland. Insufficient information is available to evaluate carbon stocks in biomass for this land classification. Consequently, it was not included in the analysis.

The change in dead organic matter as a consequence of *Land Converted to Settlements* is estimated by:

$$\varDelta C_{DOM} = \frac{\left(C_n - C_o\right) \cdot A_{ON}}{T_{ON}}$$

- ΔC_{DOM} = Annual change in carbon stocks in dead wood or litter, tonnes C yr^{-}
- C_o = Dead wood/litter stock, under old land-use category, tonnes C yr^{-}
- C_n = Dead wood/litter stock, under new land-use category, tonnes C yr^{-}
- A_{on} = Area undergoing conversion from old to new land-use category, h
- T_{on} = Time period of transition, default is 1 year for carbon losses

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[119] U.S. Department of Agriculture, Natural Resources Conservation Service. 2003. *2003 National Resources Inventory*. Available at: http://www.nrcs.usda.gov/technical/NRI/

[120] U.S. Department of Agriculture, Natural Resources Conservation Service. 2003. *2003 National Resources Inventory*. p. 1. "The rate of [forestland, cropland, pastureland, rangeland, and other] development between 1997 and 2001 averaged 2.2 million acres per year." Available at: http://www.nrcs.usda.gov/technical/NRI

Key assumptions based on the 2006 IPCC Guidelines are that for a Tier 1 approach, C_n for developed land is zero. The 2006 IPCC Guidelines provide estimates for dead wood/litter (C_o) for forest land only. For other land classes, the estimates for C_o is zero. The estimates for A_{on} are based on the same information used for the biomass pool.

The carbon emissions attributable to greenfield development shown in Table 13 represent an estimate of the aggregate from cropland, grassland, and forestland conversion. However, the magnitude of impacts from greenfield development vary as a consequence of the degree of disturbance of the above- and below-ground carbon pools and the location of impact (e.g., original carbon content of the soil and biomass, which varies by ecoregion). The current analysis estimates that land-use conversion results in aggregate losses of approximately 25%, 50%, and 70% of the estimated terrestrial carbon pool of cropland, grassland, and forestland, respectively.

BUILDING HVAC AND LIGHTING

Table 14: Emissions Related to Building HVAC and Lighting

Source	*Sector*	Emissions ($MMTCO_2E$)
Residential HVAC and lighting combustion	*Residential*	234.6
Residential HVAC and lighting electricity use	*Electric Power*	598.5
Commercial HVAC and lighting combustion	*Commercial*	166.9
Commercial HVAC and lighting electricity use	*Electric Power*	639.7
Upstream industrial sector fossil fuel combustion	*Industry*	78.9
Total Emissions from Building HVAC and Lighting		1,719

Approximately 1,719 $MMTCO_2E$, or 25% of total GHG emissions are associated with Building HVAC and Lighting. This includes the emissions resulting from heating, cooling, ventilation, and lighting residential and commercial buildings, and from extracting and processing fossil fuels used by those activities. Prevention-oriented policies to reduce Building HVAC and Lighting emissions include activities that promote building design which takes better advantage of natural light and climate control, more compact building design, and increased energy efficiency of buildings and lighting.

To calculate the emissions associated with Building HVAC and Lighting, the total emissions associated with building energy use for both the residential and commercial economic sectors first had to be calculated. The emissions from residential and commercial electricity use are taken from the Inventory's Table 2-14. These emissions are added to the sectors' direct emissions, which is the sum of the emissions from stationary and fossil fuel combustions found in the Inventory's Table 2-12. These are the total emissions associated with building energy use of the residential and commercial economic sectors. These emissions are apportioned according to their sector's relative use of energy for Building HVAC and Lighting.

End-use data from the EIA were used to establish the total energy use for Building HVAC and Lighting in commercial and residential buildings.[121] The raw data are converted to proportions in order to apply

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[121] U.S. Department of Energy, Energy Information Agency. 2008. *Commercial Buildings Energy Consumption Survey.* Available at: http://www.eia.doe.gov/emeu/cbecs/contents.html; U.S. Department of Energy, Energy Information Agency. 2005. *Residential Energy Consumption Survey*. Available at: http://www.eia.doe.gov/emeu/recs/contents.html

the findings across year-specific data.[122] The EIA data reports the end-use in British thermal units (Btu) for several categories. The building energy use categories that are considered part of Building HVAC and Lighting are: space heating, cooling, ventilation, water heating, and lighting. These categories are commonly reported between the commercial and residential sectors, with the exception of lighting. The remainder of the categories is captured in the Use of Appliances and Devices pie chart slice.

EIA's 2005 data couples residential lighting energy use with the energy use of other household appliances. The total energy use for lighting and other household appliances was 2.74 quadrillion Btu.[123] Residential lighting accounts for 8.8% of the total household electricity use.[124] The proportion of electricity used by a household for lighting, relative to total household electricity use, is applied to the total energy used by the residential sector for lighting and other household appliances. The total energy used by the residential sector for lighting is approximately 0.24 quadrillion Btu, which means that approximately 2.5 quadrillion Btu are used for other household appliances.

In 2005, the total energy used by the residential sector was 10.55 quadrillion Btu; the total energy used for HVAC and lighting was 7.53 quadrillion Btu.[125] This puts the proportion of energy used by the residential sector for Building HVAC and Lighting at about 71%. According to the EIA, the commercial sector used a total of 6,523 trillion Btu in 2003.[126] The amount of energy used for commercial Building HVAC and Lighting was 5,158 Btu, or approximately 79% of the total energy used. These proportions are applied to the building energy emissions totals for their respective sector. The resulting data are summed showing that the energy used by the commercial and residential sectors for Building HVAC and Lighting is associated with approximately 1,646 MMTCO$_2$E, or 75% of the total emissions associated with the sector's building energy use. This proportion is applied to the total fossil fuel extraction and processing emissions associated with building energy use. For example, the proportion of total electricity power industry emissions applied to Building HVAC and Lighting is also applied to methane emissions from coal mines (because the coal goes to produce electricity used by buildings). Fossil fuel extraction and processing emissions are described above in the Provision of Goods section.

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[122] This assumes that recent end-use patterns have not changed drastically.

[123] U.S. Department of Energy, Energy Information Agency. 2005. *Residential Energy Consumption Survey*. Table US12. Available at: http://www.eia.doe.gov/emeu/recs/recs2005/c&e/detailed_tables2005c&e.html

[124] U.S. Department of Energy, Energy Information Agency. 2001. "End-Use Consumption of Electricity 2001." *Residential Energy Consumption Survey*. Table 2. Available at: http://www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html

[125] U.S. Department of Energy, Energy Information Agency. 2005. *Residential Energy Consumption Survey*. Table US12. Available at: http://www.eia.doe.gov/emeu/recs/recs2005/c&e/detailed_tables2005c&e.html

[126] U.S. Department of Energy, Energy Information Agency. 2008. *Commercial Buildings Energy Consumption Survey.* Table E1.A. Available at: http://www.eia.doe.gov/emeu/cbecs/contents.html

USE OF APPLIANCES AND DEVICES

Table 15: Emissions Related to Use of Appliances and Devices

Source	*Sector*	Emissions ($MMTCO_2E$)
Residential appliances and devices combustion	*Residential*	95.8
Residential appliances and devices electricity use	*Electric Power*	244.5
Commercial appliances and devices combustion	*Commercial*	44.4
Commercial appliances and devices electricity use	*Electric Power*	170.1
Upstream industrial sector fossil fuel combustion	*Industry*	26.3
Total Emissions from Use of Appliances and Devices		581

Approximately 581 $MMTCO_2E$, or 8% of total GHG emissions are associated with commercial and residential use of appliances and devices. This includes the emissions resulting from washing clothing, cooking, refrigeration, office equipment, computers and other appliances, and fossil fuel extraction and processing.

To calculate the emissions associated with the use of Appliances and Devices, the total emissions associated with building energy use for both the residential and commercial economic sectors were calculated. The emissions from residential and commercial electricity use are taken from the Table 2-14 of the Inventory. These emissions are added to the sector's direct emissions, which is the sum of the emissions from stationary and fossil fuel combustions found in the Table 2-12 of the Inventory. These emissions comprise the total emissions associated with building energy use for the residential and commercial economic sectors. These emissions are apportioned according to their sector's relative use of energy for Appliances and Devices.

Following the methodology outlined for calculating the emissions for the use of Building HVAC and Lighting described in the preceding section, the emissions for the Use of Appliances and Devices were estimated. The residential sector uses 29% of its total building energy consumption to power household appliances and devices.[127] The commercial sector uses 21% of its total building energy consumption on powering appliances and devices.[128] These proportions are applied to the building energy emissions totals for their respective sector. The resulting data are summed showing that the energy used by the commercial and residential sectors' Use of Appliances and Devices is associated with approximately 555 $MMTCO_2E$, or 25% of the total emissions associated with the building energy use of both sectors. This proportion is applied to the total fossil fuel extraction and processing emissions associated with building energy use.

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[127] U.S. Department of Energy, Energy Information Agency. 2005. *Residential Energy Consumption Survey*. Table US-12. Available at: http://www.eia.doe.gov/emeu/recs/recs2005/c&e/detailed_tables2005c&e.html

[128] U.S. Department of Energy, Energy Information Agency. 2008. *Commercial Buildings Energy Consumption Survey.* Table E1.A. Available at: http://www.eia.doe.gov/emeu/cbecs/contents.html

SECTION A-2
METHODOLOGIES SUPPORTING TOTAL TECHNICAL POTENTIAL SCENARIOS IN *OPPORTUNITIES TO REDUCE GREENHOUSE GAS EMISSIONS THROUGH MATERIALS AND LAND MANAGEMENT PRACTICES*

Section 3 of *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices* includes a number of total technical potential scenarios. The term total technical potential refers to the estimated GHG emission reductions that would occur if the scenarios presented were achieved, setting aside economic, institutional, or technological limitations. Such scenarios are a common first step in climate policy analysis and allow for the examination of the GHG reduction potential of various mitigation strategies. These total technical potential scenarios are useful for scoping the order-of-magnitude impact of an activity and for identifying areas of promise for more detailed analysis.

These scenarios suppose a change from current U.S. business-as-usual practices and provide an estimate of the potential climate-related benefits from those changes (e.g., reduction in GHG emissions measured in MMTCO$_2$E). Some scenarios represent the GHG emission reduction that could be achieved in addition to existing materials management practices (e.g., reducing packaging by 50%), while others represent the GHG emission reduction that could be achieved from existing materials management practices that are enhanced (e.g., recycle 100% of construction and demolition debris). Recognizing that achieving 100% of the benefits presented in each scenario would be challenging, this document has prepared 100%, 50%, and 25% scenarios to provide a better understanding of the scalability of each scenario. It should be noted that these reduction rates do not represent EPA goals or targets.

The scenarios selected for this document represent a range of potential reductions (e.g., 0.2 to 2,200 MMTCO$_2$E). The majority of hypothetical reductions are on the same order of magnitude as individual options identified in other climate change mitigation analyses conducted by others (e.g., see McKinsey and Company, "Reducing U.S. GHG Emissions: How Much and at What Cost?" (2007)). These scenarios can be considered a first-step analysis for identifying areas of opportunity for EPA and its partners. As we consider developing programs and policies, more detailed studies that account for economic and practical limitations and opportunities will be needed. The scenarios suggest how to direct these future efforts to pursue options with the largest impact. An analysis and explanation of each total technical potential scenario follows.

SUMMARY OF MATERIALS MANAGEMENT TOTAL TECHNICAL POTENTIAL SCENARIOS

As noted in Section 3, most reductions from materials management approaches are likely to be achieved in ways that increase materials efficiency and are, therefore, beneficial from a GHG perspective. For example, in the example below under the "Source Reduction" group—the 50% reduction in packaging could result from innovations such as developing lighter and stronger packaging material, changing distribution systems to reduce or reuse packaging, or re-purposing previously used materials (e.g., newsprint) that require fewer raw resources.

These total technical potential scenarios represents estimates of what GHG reductions would result with today's waste streams under different management scenarios relative to current practices; the estimates do not reflect observed or projected trends in materials management practices. These estimates are not projections of future GHG reduction benefits.

It is also important to note that these reductions cannot necessarily be combined additively to one another, due to interactions between the different materials, waste streams and disposal options. These estimates were prepared using EPA's WAste Reduction Model (WARM), and therefore reflect life cycle emission reductions. Finally, these estimates are based on current national average emissions for domestic production and materials use practices, and do not take into account the energy use or GHG effects of major changes to infrastructure, manufacturing processes, or transportation methods that would be necessary to approach these potential reductions. Further, they do not take into account any emissions reductions associated with non-domestic production of goods and services.

Table 16: Summary of Materials Management Total Technical Potential Scenarios

Summary of Total Technical Potential Scenarios		Estimated GHG Emission Benefit*
Source Reduction		
Reduce packaging use by:	50%	40—105 MMTCO$_2$E/yr
	25%	20—50 MMTCO$_2$E/yr
Reduce use of non-packaging paper products by**:	50%	20—70 MMTCO$_2$E/yr
	25%	10—35 MMTCO$_2$E/yr
Extend the life of personal computers by:	50%	25 MMTCO$_2$E/yr
	25%	15 MMTCO$_2$E/yr
Reuse/Recycling		
Increase recycling of construction and demolition debris to:	100%	150 MMTCO$_2$E/yr
	50%	75 MMTCO$_2$E/yr
	25%	40 MMTCO$_2$E/yr
Increase national municipal solid waste (MSW) recycling and composting rate from 2006 rate (32.5%) to:	100%	300 MMTCO$_2$E/yr
	50%	70—80 MMTCO$_2$E/yr
Increase composting of food scraps from 2006 rate (2%) to:	100%	20 MMTCO$_2$E/yr
	50%	10 MMTCO$_2$E/yr
	25%	5 MMTCO$_2$E/yr
Energy Recovery / Disposal		
Combust percentage of currently landfilled MSW:	100%	70—120 MMTCO$_2$E/yr
	50%	35—60 MMTCO$_2$E/yr
	25%	20—30 MMTCO$_2$E/yr
Combust MSW remaining if national recycling rate is increased to 50%:		65—110 MMTCO$_2$E/yr
Capture percentage of currently emitted methane at U.S. landfills for electricity generation:	100%	150 MMTCO$_2$E/yr
	50%	70 MMTCO$_2$E/yr
	25%	35 MMTCO$_2$E/yr

* Most of the total technical potential scenarios presented in this table have been rounded to one significant figure. See following subsections for more detail on these estimates.

** Non-packaging paper products include magazines and third class mail, newspaper, office paper, phonebooks, and textbooks.

SOURCE REDUCTION

Reduce packaging use

by 50% 40-105 $MMTCO_2E$ per year

by 25% 20-50 $MMTCO_2E$ per year

In order to estimate the GHG benefits from the reduction of containers and packaging, it is first necessary to estimate the amount of each material produced per year in the United States. According to EPA's 2006 Municipal Solid Waste (MSW) Facts and Figures report,[129] the following table represents the aggregate generation and recovery values for various packaging materials in the MSW stream (see Table 17). These estimates do not capture all materials that are produced (since this table only represents the generation estimates of materials that end up in the MSW stream). Packaging that is reused or recycled before entering the MSW stream (for example, reusable pallets and crates, or boxes sent business to business and recycled separately from the MSW stream) is not included here and would not be reduced under this scenario. However, considering that most packaging eventually enters the MSW stream, these values are good approximations of the total packaging materials produced in the United States.

The MSW Facts and Figures report describes "containers and packaging" as being comprised of steel, aluminum, glass, paper and paperboard, plastics, wood, and other materials. Containers and packaging comprised the largest portion of products generated, at 79.6 million tons of total MSW generation (see Table 17).

Table 17: Generation and Recovery of Products in MSW by Material, 2006
(in millions of tons and percent of generation of each product)

Containers and Packaging	Weight Generated (tons)	Weight Recovered (tons)	Recovery as a Percent of Generation
Steel	2,750,000	1,740,000	63.27%
Aluminum	1,940,000	690,000	35.57%
Glass	11,390,000	2,880,000	25.29%
Paper and Paperboard	40,440,000	23,860,000	59.00%
Plastics	14,230,000	1,510,000	10.61%
Wood	8,480,000	1,310,000	15.45%
Other Materials	390,000	Neg.	Neg.
Total Containers and Packaging	79,620,000	31,990,000	40.18%

Using the life cycle emission factors described in EPA's *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* Report[130] and subsequently used in EPA's WARM, we use the "source reduction" emission factors to calculate the reduction in GHGs from reducing the generation of packaging materials by a quarter and in half. Some material categories in the MSW Facts and Figures report are not precisely represented in WARM, so for those we use approximate matches. The proxy for "paper and paperboard" is "corrugated cardboard," for "other materials" we use "medium-density fiberboard" and for "plastics" we use the average of the emission factors for high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyethylene terephthalate (PET). A baseline scenario of the amount of materials currently recovered, landfilled, and combusted was compared to two alternative scenarios with 50% and 25% source reduction. In the

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[129] U.S. EPA. Office of Solid Waste. 2007. *Municipal Solid Waste in the United States: 2006 Facts and Figures*. Available at: http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

[130] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*. Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

alternative scenarios, after taking into account the respective percent source reduction of each material, the amount recovered, landfilled, and combusted was scaled down by 50% or 25% accordingly to evenly distribute the materials reduction among the end-of-life pathways. These calculations estimate the GHG benefits of reducing each type of packaging by 50% and 25% with the totals equal to roughly 106 million and 53 MMTCO$_2$E per year, respectively for each scenario when including the forest sequestration effect, or 41 and 20 MMTCO$_2$E per year, respectively for each scenario when excluding forest sequestration (see Tables 18 and 19).

By reducing the amount of paper products generated, there is an associated benefit of not harvesting the upstream raw materials (i.e., trees) necessary for production. In turn, there will be an increase in available virgin forest, or similarly, an increase in the average age of managed forests, enabling additional biological carbon sequestration. The high-end sequestration benefit assumes that while harvesting of trees decreases, the management of forests otherwise remains constant (e.g., trees in managed forests continue being planted and managed forests are not converted to other uses). This high-end estimate is an extrapolation of the marginal benefit of paper source reduction. A large reduction in paper demand, however, would likely change forest management practices. The low-end estimate assumes no forest carbon sequestration benefit from the reduction. The hypothetical value with respect to forest carbon is likely in between these bounds.

Table 18: GHG Benefits for the "Source Reduction" of 50% of the Annual Generation of Packaging Products in MSW in 2006

Containers and Packaging	Weight Generated (tons)	% Source Reduction	Amount Reduced (tons)	GHG Reduction Assuming Current Mix of Inputs (MTCO$_2$E) *(Including Forest Sequestration)*	GHG Reduction Assuming Current Mix of Inputs (MTCO$_2$E) *(Excluding Forest Sequestration)*
Steel	2,750,000	50 %	1,375,000	(2,692,000)	(2,692,000)
Aluminum	1,940,000	50 %	970,000	(3,355,000)	(3,355,000)
Glass	11,390,000	50 %	5,695,000	(3,053,000)	(3,053,000)
Paper and Paperboard	40,440,000	50 %	20,220,000	(77,238,000)	(18,144,000)
Plastics	14,230,000	50 %	7,115,000	(14,856,000)	(14,856,000)
Wood	8,480,000	50 %	4,240,000	(4,913,000)	1,241,000
Other materials	390,000	50 %	195,000	(321,000)	38,000
Total Containers and Packaging	79,620,000	50 %	39,810,000	(106,428,000)	(40,821,000)

Table 19: GHG Benefits for the "Source Reduction" of 25% of the Annual Generation of Packaging Products in MSW in 2006

Containers and Packaging	Weight Generated (tons)	% Source Reduction	Amount Reduced (tons)	GHG Reduction Assuming Current Mix of Inputs (MTCO$_2$E) *(Including Forest Sequestration)*	GHG Reduction Assuming Current Mix of Inputs (MTCO$_2$E) *(Excluding Forest Sequestration)*
Steel	2,750,000	25%	687,500	(1,346,000)	(1,346,000)
Aluminum	1,940,000	25%	485,000	(1,678,000)	(1,678,000)
Glass	11,390,000	25%	2,847,500	(1,527,000)	(1,527,000)
Paper and Paperboard	40,440,000	25%	10,110,000	(38,619,000)	(9,072,000)
Plastics	14,230,000	25%	3,557,500	(7,428,000)	(7,428,000)
Wood	8,480,000	25%	2,120,000	(2,456,000)	620,000
Other materials	390,000	25%	97,500	(161,000)	19,000
Total Containers and Packaging	79,620,000	25%	19,905,000	(53,214,000)	(20,411,000)

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 40-105 $MMTCO_2E$ (50% scenario) and 20-50 $MMTCO_2E$ (25% scenario).

Reduce use of non-packaging paper products

by 50%	20-70 $MMTCO_2E$ per year
by 25%	10-35 $MMTCO_2E$ per year

While containers and packaging consist of a very large portion of the MSW stream, non-packaging paper products also contribute greatly to total MSW. The estimates in Tables 20 and 21 are derived from EPA's 2006 MSW Facts and Figures report and aggregated to include five categories of non-packaging paper products including magazines/third class mail, newspaper, office paper, phonebooks, and textbooks.[131]

Using the life cycle emission factors described in EPA's *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* Report and subsequently used in EPA's WARM, the "source reduction" emission factors were employed to calculate the reduction in GHGs associated with a 50% and a 25% reduction in the use of these materials (see Tables 20 and 21), accounting for avoided emissions from production, transport, and disposal.[132] A baseline scenario of the amount of materials currently recovered, landfilled, and combusted was compared to these source reduction alternative scenarios. In the alternative scenarios, after taking into account the source reduction of 50% and 25% of each material, the amount recovered, landfilled, and combusted was scaled down by 50% and 25%, respectively, to evenly distribute the material reduction among end-of-life pathways.

The total potential GHG benefits associated with the source reduction of 50% and 25% of each of the listed materials ranges between approximately 21 to 73 $MMTCO_2E$ for the 50% scenario and 10 to 36 $MMTCO_2E$ for the 25% scenario. The high range GHG benefits (73 and 36 $MMTCO_2E$ for the 50% and 25% scenarios, respectively) of the source reduction of paper materials includes the forest sequestration effect (see Tables 20 and 21).

Table 20: GHG Benefits for the "Source Reduction" of 50% of the Annual Generation of Five Non-Packaging Paper Materials in 2006

Material	Amount Generated in MSW Stream (tons)	% Source Reduction	Amount Reduced (tons)	GHG Reduction Assuming Current Mix of Inputs ($MTCO_2E$) *(Including Forest Sequestration)*	GHG Reduction Assuming Current Mix of Inputs ($MTCO_2E$) *(Excluding Forest Sequestration)*
Magazines/Third-class Mail	8,460,000	50 %	4,230,000	(30,632,000)	(6,258,000)
Newspaper	12,360,000	50 %	6,180,000	(14,377,000)	(7,104,000
Office Paper	6,320,000	50 %	3,160,000	(20,815,000)	(5,158,000)
Phonebooks	680,000	50 %	340,000	(1,744,000)	(572,000)
Textbooks	1,130,000	50 %	565,000	(5,291,000)	(1,800,000)
Total	28,950,000	50 %	14,475,000	(72,859,000)	(20,893,000)

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[131] U.S. EPA. 2007. *Municipal Solid Waste in the United States: 2006 Facts and Figures*. Available at: http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

[132] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*. Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

Table 21: GHG Benefits for the "Source Reduction" of 25% of the Annual Generation of Five Non-Packaging Paper Materials in 2006

Material	Amount Generated in MSW Stream (tons)	% Source Reduction	Amount Reduced (tons)	GHG Reduction Assuming Current Mix of Inputs (MTCO$_2$E) *(Including Forest Sequestration)*	GHG Reduction Assuming Current Mix of Inputs (MTCO$_2$E) *(Excluding Forest Sequestration)*
Magazines/Third-class Mail	8,460,000	25 %	2,115,000	(15,316,000)	(3,129,000)
Newspaper	12,360,000	25 %	3,090,000	(7,189,000)	(3,552,000)
Office Paper	6,320,000	25 %	1,580,000	(10,408,000)	(2,579,000)
Phonebooks	680,000	25 %	170,000	(872,000)	(286,000)
Textbooks	1,130,000	25 %	282,500	(2,645,000)	(900,000)
Total	28,950,000	25 %	7,237,500	(36,430,000)	(10,447,000)

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 20-70 MMTCO$_2$E (50% scenario) and 10-35 MMTCO$_2$E (25% scenario).

Extend the life of personal computers

by 50%	25 MMTCO$_2$E per year
by 25%	15 MMTCO$_2$E per year

We estimate the GHG benefits of extending the life of personal computers (PCs) as one example of the benefits available from extending product lifetimes. Extending the life of PCs is assumed to be equivalent to reducing the production of PCs that replace those computers. The rationale for this assumption is that a 50% increase in the lifetime of a computer would lead to a reduction of replacement computer purchases. Estimates of PC sales are described in Table 22.[133]

Table 22: U.S. Total Computer Sales by Type in 2006

Computer Type	Number of Computers (millions of units)
Desktops	35.4
Portable laptops	24.3
Total PCs	59.7

The GHG benefits were calculated using the WARM estimate of the GHG emission factor for source reduction of "personal computers." In the baseline, it was assumed that 26% of the materials from desktop computers are recycled into secondary materials, 72% are landfilled, and 2% are combusted with energy recovery, based on EPA estimates (see Table 23).[134] The estimated GHG benefit assumes a source reduction of only desktop PCs in the United States and also assumes that the PCs are produced using the current mix of inputs.

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[133] U.S. EPA. 2007. *Management of Electronic Waste in the United States: Approach One.* Final Report, EPA530-R-08-009. Table 2.2, p. 9. Available at: http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm

[134] U.S. EPA. 2007. *Management of Electronic Waste in the United States: Approach Two.* Draft Final Report, EPA530-R-07-004b. Exhibit 4-4. Available at: http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm

Table 23: Baseline Scenario for Desktop PCs in the U.S. Sold in 2006

Region	PCs (tons)	Source Reduction (tons)	Recycled (tons)	Landfilled (tons)	Combusted (tons)	Total MTCO$_2$E
USA	1,317,000	0	342,000	948,000	26,000	(747,000)

A 50% increase in the average lifetime of a PC in the U.S. is assumed to be equivalent to a reduction in the manufacture of PCs of 33% of PC sales volume in 2006.[135] This is roughly translated to increasing the average life of a PC to six years, from the current four year average before reuse, storage, or disposal.[136] A 25% increase in the average lifetime of a PC in the U.S. is assumed to be equivalent to a reduction in the manufacture of PCs of 20% of PC sales volume in 2006.[137] This is roughly translated to increasing the average life of a PC to five years, from the current average of four years before reuse, storage or disposal.[138]

Of course, the benefits of improving today's computers would only accrue starting several years in the future, but this estimate can be thought of as the total benefit over time. Finally, the average weight of a typical desktop PC is assumed to be 70 pounds, and a typical laptop is assumed to be 6.4 pounds.[139] The resulting GHG benefits amount to roughly 24 and 15 million metric tons carbon dioxide equivalent (MMTCO$_2$E), respectively for each scenario, from the PCs sold in 2006 (see Table 24).

Table 24: GHG Benefits from Source Reduction of Desktop PCs in the U.S. Sold in 2006

Region	Scenario	PCs (tons)	Source Reduction (tons)	Recycled (tons)	Landfilled (tons)	Combusted (tons)	Total MTCO$_2$E	Net Difference (MTCO$_2$E)
USA	50%	878,000	439,000	228,000	632,000	18,000	(25,065,000)	(24,318,000)
USA	25%	1,043,000	274,000	271,000	751,000	21,000	(15,912,000)	(15,165,000)

This result has some caveats that are necessary to point out:

1. The WARM emissions factors used for this calculation were developed for desktop PCs with cathode ray tube (CRT) monitors. Applying these factors to laptop computers with liquid crystal display (LCD) monitors introduces some error, due to differences in the manufacturing and end-of-life management of these computers. The resulting error is likely small, since laptop computers account for roughly 6% of the total waste stream by weight.
2. In order for older computers to remain useful for an additional two years (i.e., extension of the lifetime of PCs), part replacements and upgrades may be necessary in order to remain at pace with the software and technology markets. This will further reduce the source reduction GHG

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[135] The 33% assumption comes from assuming that for every 100 computers retired under current conditions, 67 computers would be retired in the alternative scenario (based on a simple ratio of 1 / 1.5 = 0.67).

[136] U.S. EPA. 2007. *Management of Electronic Waste in the United States: Approach Two*. Draft Final Report, EPA530-R-07-004b. Exhibit 3-7. Available at: http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm

[137] The 20% assumption comes from assuming that for every 100 computers retired under current conditions, 80 computers would be retired in the alternative scenario (based on a simple ratio of 1 / 1.25 = 0.80).

[138] U.S. EPA. 2007. *Management of Electronic Waste in the United States: Approach Two*. Draft Final Report, EPA530-R-07-004b. Exhibit 3-7. Available at: http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm

[139] Franklin Associates. 2001. *Energy and Greenhouse Gas Factors for Personal Computers*. p. 3. (desktop PC weight); U.S. EPA. 2008. *Electronics Waste Management in the United States, Approach 1*. Final, EPA530-R-08-009. Table 2.7, p. 18. (laptop PC weight). Available at: http://www.epa.gov/osw/conserve/materials/ecycling/manage.htm

benefits, since this hardware will have similar energy and GHG impacts as parts in new computers.

3. If users delay the purchase of newer, more energy efficient models, some source reduction GHG benefits will be lost due the extended lifetime of the more energy intensive models. As manufacturers place more emphasis on energy efficiency of new models, the prolonged use of older models will result in the consumption of more electricity during the "product use" phase of the computer's life cycle. On the other hand, if new computers are more energy intensive than previous models (for example, as a result of multi-core processors), there may be additional GHG benefits associated with the increased lifetime of newer PCs.

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 25 MMTCO$_2$E (50% scenario) and 15 MMTCO$_2$E (25% scenario).

Increase recycling of construction and demolition debris materials

to 100%	150 MMTCO$_2$E per year
to 50%	75 MMTCO$_2$E per year
to 25%	40 MMTCO$_2$E per year

EPA's *Characterization of Building Related Construction and Demolition Debris in the United States,* ("the construction and demolition (C&D) Characterization Report") was used as the primary data source for estimating the potential GHG reduction from recycling C&D waste.[140] WARM was then used to quantify the GHG reductions from recycling all cardboard, lumber, metal, plastic, concrete, and clay bricks.

Table ES-1 from the C&D Characterization Report provides estimates of the breakdown of the total C&D waste stream into construction, renovation, and demolition in residential and nonresidential sectors in 1996 (see Table 25).

Table 25: U.S. Construction, Renovation, and Demolition Waste by Sector

Waste Type	Residential		Nonresidential		Total	
	tons	% of total	tons	% of total	tons	% of total
Construction	6,560,000	11%	4,270,000	6%	10,830,000	8%
Renovation	31,900,000	55%	28,000,000	36%	59,900,000	44%
Demolition	19,700,000	34%	45,100,000	58%	64,800,000	48%
Total	58,160,000		77,370,000		135,530,000	

Next, the results of a C&D characterization study in Des Moines, Iowa, conducted by EPA in 1998 (Table A-17), were used to estimate the composition of each of the above waste streams (see Table 26).[141]

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[140] U.S. EPA. Office of Solid Waste, Municipal and Industrial Solid Waste Division. 1998. *Characterization of Building Related Construction and Demolition Debris in the United States*. Report No. EPA530-R-98-010.

[141] Ibid.

Table 26: Composition of C&D Waste Streams

Material	Residential			Commercial		
	New Construction	Renovation	Demolition	Construction	Renovation	Demolition
Asphalt	0%	0%	0%	1%	0%	0%
Brick	5%	4%	4%	7%	5%	7%
Cardboard	4%	2%	0%	7%	1%	1%
Concrete	12%	9%	22%	33%	22%	32%
Drywall	16%	5%	10%	7%	16%	20%
Metal	2%	10%	5%	9%	13%	12%
Plastic	1%	1%	0%	0%	0%	0%
Roofing	6%	29%	17%	10%	10%	3%
Wood	44%	30%	32%	19%	18%	25%
Other	10%	11%	9%	8%	15%	0%

The tonnages in Table 25 were then multiplied by the percentages in Table 26 for material components in order to estimate the volume of each material, as shown in Table 27.

Table 27: U.S. Construction, Renovation, and Demolition Waste by Sector and Material

Material	Residential (tons)			Nonresidential (tons)			Total (thousand tons)
	New	Renovation	Demolition	New	Renovation	Demolition	
Asphalt	-	-	-	26,000	-	-	26,000
Brick	341,000	1,228,000	774,000	286,000	1,275,000	3,353,000	7,258,000
Cardboard	292,000	625,000	86,000	319,000	403,000	671,000	2,396,000
Concrete	796,000	2,896,000	4,301,000	1,406,000	6,094,000	14,251,000	29,744,000
Drywall	1,067,000	1,714,000	2,065,000	280,000	4,371,000	8,886,000	18,383,000
Metal	103,000	3,035,000	946,000	378,000	3,588,000	5,365,000	13,414,000
Plastic	57,000	208,000	86,000	20,000	60,000	-	431,000
Roofing	368,000	9,104,000	3,269,000	410,000	2,931,000	1,341,000	17,424,000
Wood	2,909,000	9,521,000	6,366,000	801,000	5,064,000	11,233,000	35,895,000
Other	627,000	3,568,000	1,807,000	345,000	4,214,000	-	10,560,000
Total	6,560,000	31,900,000	19,700,000	4,270,000	28,000,000	45,100,000	135,530,000

Next, the total volumes for cardboard, concrete, clay bricks, metal, plastic, and wood were entered into WARM. Since data on the current end-of-life treatment of C&D wastes were not available, the approach assumed that all C&D materials are 100% landfilled in the baseline, and that 100%, 50%, or 25% of the cardboard, concrete, metal, plastic and wood waste tonnage are recycled in the alternative scenarios. Clay bricks were assumed to be reused to offset the need for new bricks. The benefits of recycling asphalt, drywall, roofing, and the "other" categories of C&D materials were not calculated because recycling emission factors were not available for these streams. Tables 28 through 30 display the WARM outputs for the baseline and alternative (recycling or source reduction) scenarios, and the results of the alternatives minus baseline, to give the net difference.

Table 28: Baseline and 100% Alternative Scenario and Net Difference for C&D Recycling vs. Landfilling

Material	Baseline		Alternative (100%)		Net Difference
	Tons Landfilled	Total MTCO$_2$E	Tons Recycled	Total MTCO$_2$E	Total MTCO$_2$E
Corrugated Cardboard	2,396,000	797,000	2,396,000	(7,454,000)	(8,251,000)
Dimensional Lumber (Wood)	35,895,000	(18,757,000)	35,895,000	(88,129,000)	(69,372,000)
Mixed Metals	13,414,000	515,000	13,414,000	(70,523,000)	(71,038,000)
Clay Bricks[142]	7,258,000	279,000	7,258,000	(2,075,000)	(2,354,000)
Mixed Plastics	431,000	17,000	431,000	(656,000)	(673,000)
Concrete	29,744,000	1,142,000	29,744,000	(233,000)	(1,375,000)
Total		(16,007,000)		(169,070,000)	(153,063,000)

Table 29: Baseline and 50% Alternative Scenario and Net Difference for C&D Recycling vs. Landfilling

Material	Baseline		Alternative (50%)		Net Difference
	Tons Landfilled	Total MTCO$_2$E	Tons Recycled	Total MTCO$_2$E	Total MTCO$_2$E
Corrugated Cardboard	2,396,000	797,000	1,198,000	(3,329,000)	(4,126,000)
Dimensional Lumber (Wood)	35,895,000	(18,757,000)	17,947,500	(53,443,000)	(34,686,000)
Mixed Metals	13,414,000	515,000	6,707,000	(35,004,000)	(35,519,000)
Clay Bricks[143]	7,258,000	279,000	3,629,000	(898,000)	(1,177,000)
Mixed Plastics	431,000	17,000	215,500	(320,000)	(337,000)
Concrete	29,744,000	1,142,000	14,872,000	454,000	(688,000)
Total		(16,007,000)		(92,540,000)	(76,533,000)

Table 30: Baseline and 25% Alternative Scenario and Net Difference for C&D Recycling vs. Landfilling

Material	Baseline		Alternative (25%)		Net Difference
	Tons Landfilled	Total MTCO$_2$E	Tons Recycled	Total MTCO$_2$E	Tons Landfilled
Corrugated Cardboard	2,396,000	797,000	599,000	(1,266,000)	(2,063,000)
Dimensional Lumber (Wood)	35,895,000	(18,757,000)	8,973,750	(36,100,000)	(17,343,000)
Mixed Metals	13,414,000	515,000	3,353,500	(17,245,000)	(17,760,000)
Clay Bricks[144]	7,258,000	279,000	1,814,500	(152,000)	(589,000
Mixed Plastics	431,000	17,000	107,750	(310,000)	(169,000))
Concrete	29,744,000	1,142,000	7,436,000	798,000	(344,000)
Total		(16,007,000)		(54,275,000)	(38,268,000)

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[142] Used bricks were assumed to be reused (i.e., source reduced) to offset the demand for new bricks.

[143] Used bricks were assumed to be reused (i.e., source reduced) to offset the demand for new bricks.

[144] Used bricks were assumed to be reused (i.e., source reduced) to offset the demand for new bricks.

These estimates have a very high level of uncertainty due to the lack of comprehensive data quantifying and characterizing the national C&D waste stream. Some of the factors contributing to uncertainty in this area include:

1) The total C&D waste stream estimate is based on the 1998 EPA study. Until better data are available, this is the only source available for characterizing this waste sector. Given the significant uncertainty with the older values, the estimates were not scaled up to 2006 to avoid introducing more error into the process.
2) The composition of each of the six sub-streams (residential and non-residential construction, demolition, and renovation) is based on a study over a single week in Des Moines, Iowa in 1995. There are huge regional variations in composition. For example, wood is more common in the Northwest than in the Southwest, and Northern regions tend to have full concrete basements, while many Southern or Western regions do not.
3) Not all materials in the C&D waste stream can be represented in WARM. For example, WARM does not include GHG factors for recycling asphalt shingles or gypsum wallboard.
4) Many of the recycling pathways covered by WARM may not be applicable to C&D waste. Lumber from new construction may be easily recycled, while wood waste from demolition and renovation often ends up as mulch or is burned for fuel.
5) It is also not possible to say how much these potential savings compare with existing practices. The same C&D study estimates recycling at 30-40% with no details on the recycling rates of individual materials. One industry group estimates steel recycling at 85%, so the marginal benefits likely vary by material.

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 150 MMTCO$_2$E (100% scenario), 75 MMTCO$_2$E (50% scenario), and 40 MMTCO$_2$E (25% scenario).

Increase national MSW recycling and composting rate from 2006 rate (32.5%)

to 100%	300 MMTCO$_2$E per year
to 50%	70-80 MMTCO$_2$E per year

According to EPA's 2006 MSW Facts and Figures report,[145] the total MSW stream was 251,330,000 tons in 2006, as shown in the second column of Table 31 below. The report also provides the portions of waste generated that are recovered as shown in the same table. This analysis assumed that all materials that were "recovered" were recycled, except for recovered organic waste streams, which were assumed to be composted. One other exception is the "mixed MSW" material type which cannot be recovered and whose recovery amount is assumed to be landfilled in both the baseline and alternative scenarios. The tonnage of discarded materials that were landfilled or combusted for energy, shown in Table 31, were estimated by applying the percentages of total MSW discarded that were landfilled or combusted (80% and 20%, respectively) to the discarded totals for the recyclable materials. These percentages were estimated using the tonnage data presented in Table 29 of EPA's 2006 MSW Facts and Figures report.

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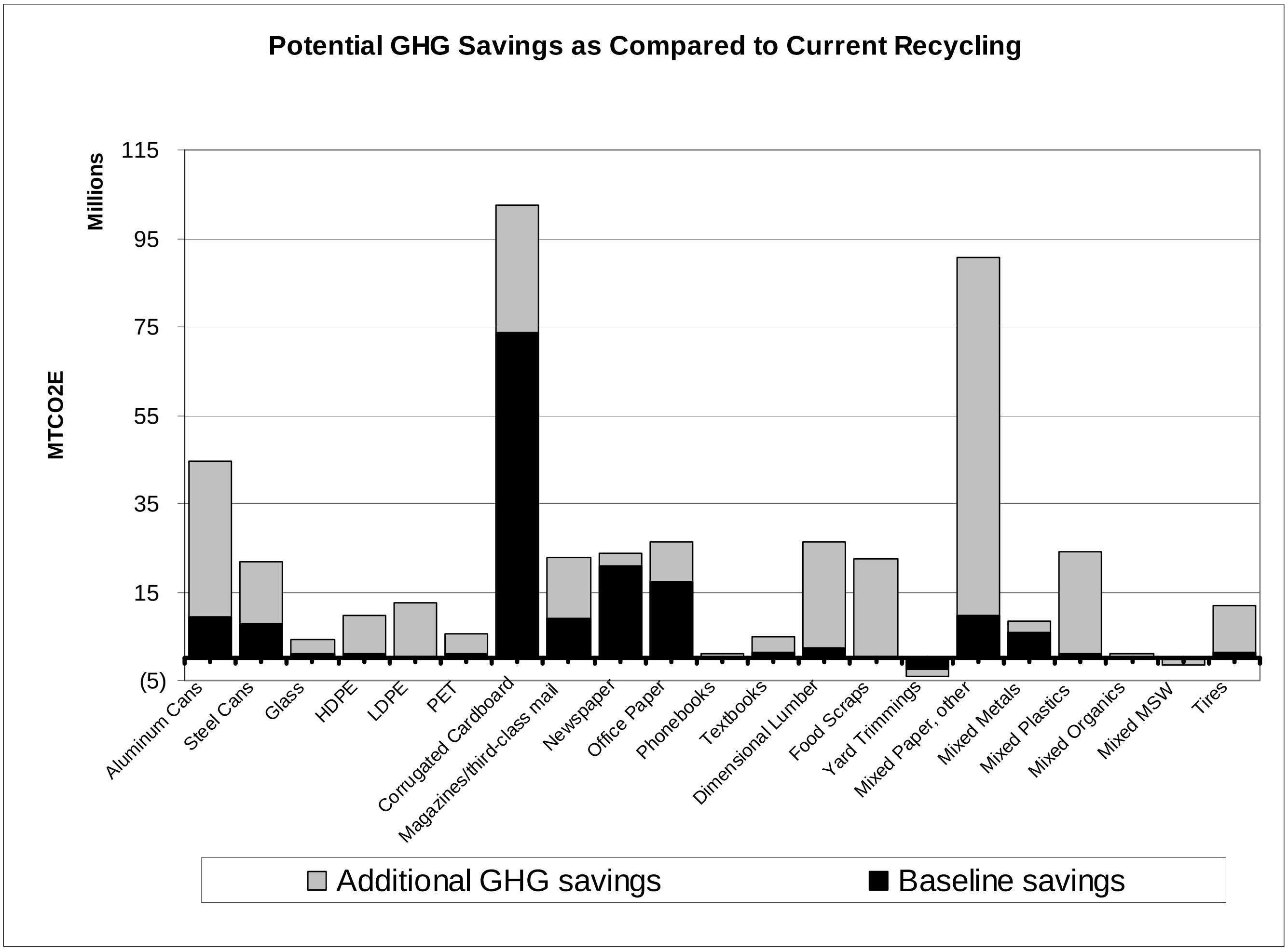
[145] U.S. EPA. 2007. *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2006*. Table 1. Available at: http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/06data.pdf

Table 31: Baseline Scenario for All MSW Materials

Material	Tons Waste Generated	Tons Recovered	Recovery Rate	Tons Landfilled	Tons Combusted for Energy
Aluminum	3,260,000	690,000	21.2%	2,094,000	476,000
Steel	14,220,000	5,080,000	35.7%	7,448,000	1,692,000
Glass	13,200,000	2,880,000	21.8%	8,410,000	1,910,000
HDPE	6,040,000	580,000	9.6%	4,449,000	1,010,000
LDPE	6,560,000	280,000	4.3%	5,118,000	1,162,000
PET	3,060,000	620,000	20.3%	1,988,000	451,000
Corrugated Cardboard	31,430,000	22,630,000	72.0%	7,171,000	1,629,000
Magazines/ Third-class Mail	8,460,000	3,320,000	39.2%	4,189,000	951,000
Newspaper	12,360,000	10,870,000	87.9%	1,214,000	276,000
Office Paper	6,320,000	4,150,000	65.7%	1,768,000	402,000
Phonebooks	680,000	130,000	19.1%	448,000	102,000
Textbooks	1,130,000	290,000	25.7%	685,000	155,000
Mixed Paper, other	24,900,000	2,630,000	10.6%	18,148,000	4,122,000
Dimensional Lumber	13,930,000	1,310,000	9.4%	10,284,000	2,336,000
Food Scraps	31,250,000	680,000	2.2%	24,912,000	5,658,000
Yard Trimmings	32,400,000	20,100,000	62.0%	10,024,000	2,276,000
Mixed Metals	1,650,000	1,180,000	71.5%	383,000	87,000
Mixed Plastics	13,830,000	560,000	4.0%	10,814,000	2,456,000
Mixed Organics	3,720,000	0	0.0%	3,032,000	688,000
Mixed MSW	16,390,000	2,940,000	17.9%	10,961,000	2,489,000
Tires	6,540,000	870,000	13.3%	4,621,000	1,049,000
Total	251,330,000	81,790,000	32.5%	138,162,000	31,378,000

It is useful to estimate the GHG savings that are hypothetically possible in a scenario with 100% recovery in order to identify areas of opportunity. The following graph shows the GHG savings per material from increasing each material's recovery rate from 0% assuming all materials are either landfilled or combusted (80% and 20%, respectively) to 100% recovery (again, except for "mixed MSW" which is assumed to be landfilled). The total potential GHG savings from 100% recovery (assuming this 0% scenario) is 460 $MMTCO_2E$. The current recovery of MSW as shown in Table 31 is roughly 32.5% across all materials. Therefore, the baseline MSW recovery scenario is already producing GHG savings of roughly 160 $MMTCO_2E$ across all materials as compared to a 0% scenario. The total potential additional GHG savings from increasing the recovery rate from the current baseline (32.5%) to the hypothetical maximum (100%) is roughly 300 $MMTCO_2E$. These added GHG savings are shown per material in Figure A.

Figure A: GHG Savings for Current Baseline Rate (32.5%) and Total Potential (100%) as Compared to No Recovery



The increase of the national average recycling rate (including composting) to 50% across all materials in the MSW stream is complicated because each material has its own individual recovery rate, as shown in Table 31. The 2006 baseline weighted average across all materials is roughly 32.5% with individual materials ranging from 2 to 88%. To simplify this analysis, two alternative scenarios were considered which both achieved a national recycling rate of 50% but differed in the allocation of the individual materials recovery rates. Neither of these allocations reflects a likely approach for achieving this magnitude of increase in the national recovery rate for MSW. However, together they provide a range to illustrate the magnitude of potential GHG reductions associated with such an increase.

Alternative 1 assumes that all materials adjust their recovery rates to 50%, including those with rates above 50%. In this scenario, materials with current recovery rate higher than 50% such as corrugated cardboard and newspaper would decrease to 50%, thus actually increasing GHG emissions for these materials. Other materials with recovery rates below 50% would achieve a 50% recovery rate and would therefore reduce GHG emissions. The remaining unrecovered materials would again be allocated to either the landfill or combustion facility (80% and 20%, respectively). Overall, this Alternative 1 scenario would achieve total GHG reductions of 68,130,000 $MTCO_2E$ as compared to the current baseline shown in Table 32.

Alternative 2 assumes a linear increase for each material type based on total weight generated such that the total recycling rate is equal to 50%. In other words, each material type would increase its individual recovery rate by 17.5%. The only exception is newspaper, which is capped at 100%. The remaining unrecovered materials would again be allocated to either the landfill or combustion facility (80% and 20%, respectively). Overall, the Alternative 2 scenario would achieve total GHG reductions of 78,981,000 $MTCO_2E$ as compared to the current baseline shown in Table 32.

Increasing the national MSW recycling rate to 50% produces a GHG benefit of roughly 70 to 80 $MMTCO_2E$. Actual reductions will depend on the mix of materials recycled.

Table 32: Alternative Scenarios for all MSW Materials and Total GHG Reductions

Material	Tons Waste Generated	Alternative 1 Recovery Rate	Alternative 2 Recovery Rate	Alternative 1 GHG Reduction ($MTCO_2E$)	Alternative 2 GHG Reduction ($MTCO_2E$)
Aluminum	3,260,000	50.0%	38.6%	12,891,000	7,804,000
Steel	14,220,000	50.0%	53.2%	3,133,000	3,831,000
Glass	13,200,000	50.0%	39.3%	1,189,000	736,000
HDPE	6,040,000	50.0%	27.1%	3,910,000	1,690,000
LDPE	6,560,000	50.0%	21.7%	5,722,000	2,184,000
PET	3,060,000	50.0%	37.7%	1,620,000	951,000
Corrugated Cardboard	31,430,000	50.0%	89.5%	(22,543,000)	17,887,000
Magazines/ Third-class Mail	8,460,000	50.0%	56.7%	2,471,000	4,010,000
Newspaper	12,360,000	50.0%	100.0%	(9,064,000)	2,880,000
Office Paper	6,320,000	50.0%	83.1%	(4,130,000)	4,603,000
Phonebooks	680,000	50.0%	36.6%	377,000	213,000
Textbooks	1,130,000	50.0%	43.1%	1,218,000	874,000
Mixed Paper, Other	24,900,000	50.0%	28.0%	35,703,000	15,804,000
Dimensional Lumber	13,930,000	50.0%	26.9%	10,653,000	4,581,000
Food Scraps	31,250,000	50.0%	19.6%	10,747,000	3,923,000
Yard Trimmings	32,400,000	50.0%	79.5%	483,000	(701,000)
Mixed Metals	1,650,000	50.0%	89.0%	(1,807,000)	1,466,000
Mixed Plastics	13,830,000	50.0%	21.5%	11,024,000	4,188,000
Mixed Organics	3,720,000	50.0%	17.5%	527,000	184,000
Mixed MSW	16,390,000	50.0%	35.4%	(480,600)	(262,000)
Tires	6,540,000	50.0%	30.8%	4,489,000	2,135,000
Total	251,330,000	50.0 %	49.7%	68,130,000	78,981,000

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 300 $MMTCO_2E$ (100% scenario), and 70-80 $MMTCO_2E$ (50% scenario).

Increase composting of food scraps from 2006 rate (2%)

to 100%	20 $MMTCO_2E$ per year
to 50%	10 $MMTCO_2E$ per year
to 25%	5 $MMTCO_2E$ per year

In 2006, 31,250,000 tons of food waste were generated in the U.S. according to the EPA's 2006 MSW Facts and Figures report.[146] Of that total, 30,570,000 tons were discarded and the remaining 680,000 tons were recovered. Applying estimated percentages of the proportions of discarded MSW that were combusted for energy or landfilled—20% and 80%, respectively—in 2006 to the 30,570,000 tons of food waste discarded, we estimate that 5.6 and 24.9 million tons of food waste were combusted for energy and landfilled, respectively in 2006. We assumed that all recovered food waste was composted.

Table 33 below shows the waste management tonnages for food waste for this 2006 baseline scenario. In the alternative scenarios, shown in Table 34, we assume that 100%, 50%, and 25% of the total tonnage of food scraps generated is composted and that the remainder is landfilled or combusted. These volumes for the baseline and three alternative scenarios were entered into WARM.

Table 33: Baseline Scenario for Food Waste Management in 2006

Material	Tons Waste Generated	Tons Recovered	Tons Composted	Tons Discarded	Tons Landfilled	Tons Combusted for Energy	Total $MTCO_2E$
Food Waste	31,250,000	680,000	680,000	30,570,000	24,912,000	5,658,000	15,792,000

Table 34: Alternative Scenarios Assuming 100%, 50%, and 25% of Generated Food Waste Composted and Net Difference between Alternative and Baseline

Material	Percent Composted	Tons Waste Generated	Tons Composted	Total $MTCO_2E$	Net Difference ($MTCO_2E$)
Food Waste	100%	31,250,000	31,250,000	(6,192,000)	(21,984,000)
Food Waste	50%	31,250,000	15,625,000	5,045,000	(10,747,000)
Food Waste	25%	31,250,000	7,813,000	10,663,000	(5,129,000)

Tables 33 and 34 also display the WARM outputs in $MTCO_2E$ for the baseline and alternative scenarios, and the results of the alternatives minus the baseline, to give the net differences. Composting 100% of the food waste results in a GHG reduction of approximately 22 $MMTCO_2E$, and would require roughly a 45-fold increase in the current level of food composting. Note that this WARM run assumed the national average of landfill gas recovery and default landfill gas collection system efficiency, and used the default transportation distances to the various waste management facilities. Assuming no landfill gas recovery (which would increase the emissions in the baseline), would produce a GHG benefit of 40 $MMTCO_2E$ from composting all food scraps. This calculation does not account for all of the benefits associated with what the compost may be used for, (e.g., avoiding commercial fertilizer production or increasing plant growth).

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[146] U.S. EPA. Office of Solid Waste. 2007. *Municipal Solid Waste in the United States: 2006 Facts and Figures*. Available at: http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 20 MMTCO$_2$E (100% scenario), 10 MMTCO$_2$E (50% scenario), and 5 MMTCO$_2$E (25% scenario).

ENERGY RECOVERY/DISPOSAL

Combust percentage of currently landfilled MSW

100%	70-120 MMTCO$_2$E per year
50%	35-60 MMTCO$_2$E per year
25%	20-30 MMTCO$_2$E per year

The tonnage of waste landfilled was 138,170,000 in 2006, according to EPA's 2006 MSW Facts and Figures report.[147,148] WARM was used to quantify the difference between the baseline scenario of landfilling this amount of mixed MSW (assuming current mix of virgin and recycled inputs) using the national average of landfill conditions,[149] and alternative scenarios where 100%, 50%, and 25% of this quantity is instead combusted for energy recovery for use in electricity generation. As Table 35 indicates, combusting varying percentages of the 138,170,000 tons of mixed MSW for energy recovery compared to landfilling this quantity results in a net GHG benefit of approximately 68, 34, and 17MMTCO$_2$E, respectively for each scenario, in 2006.

Table 35: Baseline and Alternative Scenarios and Net Difference for Combusting 100%, 50%, and 25% of Landfilled MSW (Based on EPA's 2007 Facts and Figures Report)

Material	Baseline (National Average LFG Recovery)		Alternative			Net Difference
	Tons Landfilled	Total MTCO$_2$E	Percent Combusted	Tons Combusted	Total MTCO$_2$E	Total MTCO$_2$E
Mixed MSW	138,170,000	50,679,000	100%	138,170,000	(17,598,000)	(68,276,000)
Mixed MSW	138,170,000	50,679,000	50%	69,085,000	16,540,000	(34,138,000)
Mixed MSW	138,170,000	50,679,000	25%	34,542,500	33,609,000	(17,069,000)

Figures from BioCycle's Survey on the State of Garbage in America were also used as a source for the quantity of MSW currently landfilled in the U.S. According to BioCycle, 387,855,461 tons of MSW were generated in 2004, and of this amount, 248,615,350 tons were discarded in landfills in 2004.[150] WARM was then used to quantify the difference between the baseline scenario of landfilling this amount of mixed MSW (assuming current mix of virgin and recycled inputs) using the national average of landfill conditions, and the alternative of combusting varying percentages of it as well as all of it for energy recovery.

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[147] U.S. EPA. Office of Solid Waste. 2007. *Municipal Solid Waste in the United States: 2006 Facts and Figures*. Table 29. Available at: http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

[148] Note that this quantity already excludes 31.4 million tons that are combusted for energy recovery, as reported by the 2005 MSW Facts and Figures report. In addition, this 136 million ton figure for landfilling does not include any C&D materials, since C&D is not captured in the annual MSW generation estimates presented in the 2007 MSW Facts and Figures Report.

[149] The national average of landfill conditions assumes that 25% of methane emitted from landfills is recovered for energy, 23% is flared, 5% is oxidized, and the remaining 47% is not recovered (based on U.S. EPA. 2008. *Inventory of US GHG Emissions and Sinks: 1990-2006*).

[150] 2006. "State of Garbage in America, 15th Nationwide Survey of Municipal Solid Waste Management in the United States." *BioCycle Magazine*. April 2006, pp. 26-43. Available at: http://www.biocycle.net/

As shown below in Table 36, we estimate that if 100%, 50%, and 25% of the approximately 248,615,000 tons of mixed MSW (based on BioCycle data for 2004) were combusted for energy recovery instead of being landfilled, the net GHG benefit is roughly 123, 61, and 31 MMTCO$_2$E for each scenario, respectively.

Table 36: Baseline and Alternative Scenarios and Net Difference for Combusting 100%, 50%, and 25%of Landfilled MSW (Based on Estimates from BioCycle Survey: The State of Garbage in America 1989 - 2004)

Material	Baseline (National Average LFG Recovery)		Alternative			Net Difference
	Tons Landfilled	Total MTCO$_2$E	Percent Combusted	Tons Combusted	Total MTCO$_2$E	Total MTCO$_2$E
Mixed MSW	248,615,000	91,188,000	100%	248,615,000	(31,664,000)	(122,852,000)
Mixed MSW	248,615,000	91,188,000	50%	124,308,000	29,762,000	(61,426,000)
Mixed MSW	248,615,000	91,188,000	25%	62,154,000	60,475,000	(30,713,000)

Utilizing both EPA and BioCycle data, which include different wastes and secondary materials, make it possible to account for some of the variation found in alternative data sources, and allows us to establish upper and lower-bound estimates of the GHG mitigation that may be possible through combustion with energy recovery. Our estimates reveal that, based on national average conditions, the GHG mitigation benefits of diverting 100%, 50%, or 25% of the discarded MSW from landfills to combustion for energy recovery would range from 68 to 123 MMTCO$_2$E, 34 to 61 MMTCO$_2$E, or 17 to 31 MMTCO$_2$E, respectively.

The GHG benefits calculated for these scenarios assume that all of the energy recovered from combustion is used to offset electricity consumption from the power grid. The avoided GHG emissions from this displaced electricity use are calculated at the marginal GHG emission rate, which is the average mix of fossil fuel power generation in the U.S.[151] The range described by this hypothetical scenario corresponds to roughly a four- to eight-fold increase in MSW energy currently consumed in the U.S.,[152] assuming an average energy content of 10 million BTU per ton of mixed MSW.

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 70-120 MMTCO$_2$E (100% scenario), 35-60 MMTCO$_2$E (50% scenario), and 20-30 MMTCO$_2$E (25% scenario).

Combust MSW remaining if national recycling rate is increased to 50% 65-110 MMTCO$_2$E per year

This estimate follows the same methodology as the scenario above, but assumes that an additional tonnage of MSW is diverted before combustion bringing the national recycling and composting rate to 50% (reducing the tonnage of MSW available for combustion with energy recovery).

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[151] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*. p. ES-9, which indicates "when estimating the GHG emission reductions attributable to utility emissions avoided, the electricity use displaced by waste management practices is assumed to be 100 percent fossil-derived, since fossil-based power plants typically operate at the margin, adjusting to conform to the demand for electricity." Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

[152] U.S. Department of Energy, Energy Information Agency. 2006. *Renewable Energy Trends in Consumption and Electricity*. Table 1.7. Available at http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends.html. Assumes that the non-biogenic portion accounts for 50% of the energy content of the total MSW waste stream, as estimated in Table B2 on p. 17 of EIA 2007 *Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy*. Available at: http://www.eia.doe.gov/cneaf/solar.renewables/page/mswaste/msw_report.html

Capture percentage of currently emitted methane at U.S. landfills for electricity generation

100%	150 MMTCO$_2$E per year
50%	70 MMTCO$_2$E per year
25%	35 MMTCO$_2$E per year

The amount of methane generated in all U.S. landfills in 2006 was 265 MMTCO$_2$E according to the U.S. GHG Inventory.[153] Of this, 25% of methane generated in landfills is recovered for energy, 23% is flared, 5% is oxidized to CO$_2$, and the remaining 47% is emitted to the atmosphere. This current baseline (see Table 37) was compared with several alternatives where 100%, 50%, and 25% of the methane generated in U.S. landfills that is not oxidized to CO$_2$ is captured and recovered for electricity generation.

For the current baseline and the alternative scenarios, avoided emissions from electric utilities were calculated to account for the electricity produced by recovering landfill gas. In all scenarios, it was assumed that all of the recovered landfill gas was used to offset electricity production at the marginal GHG emission rate for the U.S., which is the average mix of fossil fuel power generation.[154]

Table 37: Baseline for Landfill Gas Recovery in 2006

Material	Methane Generation (MTCO$_2$E)	Methane Reduction (MTCO$_2$E)			Net Methane Emissions (MTCO$_2$E)	Utility Emissions Avoided from Energy Recovery (MTCO$_2$E)	Total MTCO$_2$E
		Recovered for Electricity Generation	Flared	Oxidized			
Mixed MSW	264,800,000	(65,300,000)	(59,800,000)	(14,000,000)	125,700,000	(8,569,000)	117,131,000

Table 38: Alternative Scenarios Assuming 100%, 50%, and 25% of Methane Generated at U.S. Landfills is Captured and Recovered in 2006

Material/ Scenario	Methane Generation (MTCO$_2$E)	Reduction in methane emissions (MTCO$_2$E)			Net Methane Emissions (MTCO$_2$E)	Utility Emissions Avoided from Energy Recovery (MTCO$_2$E)	Total MTCO$_2$E	Net Difference (MTCO$_2$E)
		Recovered for Electricity Generation	Flared	Oxidized				
Mixed MSW – 100% Captured	264,800,000	250,800,000	0	14,000,000	0	(32,911,000)	(32,911,000)	(150,042,000)
Mixed MSW – 50% Captured	264,800,000	128,150,000	59,800,000	14,000,000	62,850,000	(16,817,000)	46,033,000	(71,098,000)
Mixed MSW – 25% Captured	264,800,000	96,725,000	59,800,000	14,000,000	94,275,000	(12,693,000)	81,582,000	(35,549,000)

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[153] U.S. EPA. 2008. *Inventory of US GHG Emissions and Sinks: 1990-2006*. Table 8-3. Available at http://www.epa.gov/climatechange/emissions/usgginv_archive.html

[154] U.S. EPA. 2006. *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*. See page ES-9, which indicates "when estimating the GHG emission reductions attributable to utility emissions avoided, the electricity use displaced by waste management practices is assumed to be 100 percent fossil-derived, since fossil-based power plants typically operate at the margin, adjusting to conform to the demand for electricity." Available at: http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html

In the alternative scenarios, 25%, 50%, or 100% of the methane generated in U.S. landfills that is not oxidized to CO_2 is assumed to be captured and recovered for electricity with 100% capture efficiency. The total difference between the current baseline and alternative scenarios where 100%, 50%, or 25% of the methane is captured is a GHG benefit of 150, 71, or 36 MMTCO$_2$E, respectively (see Table 38).

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 150 MMTCO$_2$E (100% scenario), 70 MMTCO$_2$E (50% scenario), and 35 MMTCO$_2$E (25% scenario).

SUMMARY OF LAND MANAGEMENT TOTAL TECHNICAL POTENTIAL SCENARIOS

The land management reductions presented in this document represent hypothetical estimates of what GHG reductions would result from applying different management approaches to land. These estimates are not projections of future GHG reduction benefits. It is also important to note that these reductions cannot be combined additively to one another, due to the overlap in sites and acreage analyzed for each scenario. These estimates do not reflect life cycle emission reductions. Finally, these estimates have been calculated from a land management perspective, and do not take into account the energy use or GHG emissions resulting from changes to infrastructure, manufacturing processes, or transportation methods that would be necessary to support these hypothetical scenarios. These estimates also do not take into account the energy use or GHG emissions resulting from changes necessary to support these hypothetical scenarios.

Table 39: Summary of Land Management Total Technical Potential Scenarios

Summary of Total Technical Potential Scenarios		Estimated GHG Emission Benefit*
Land Revitalization		
Shift 60% of expected new development to compact development patterns**:		79 MMTCO$_2$E/yr
Reuse percentage of qualifying EPA-tracked contaminated land for utility-scale solar***:	100%	2,200 MMTCO$_2$E/yr
	50%	1,100 MMTCO$_2$E/yr
	25%	540 MMTCO$_2$E/yr
Reuse percentage of qualifying EPA-tracked contaminated land for community and utility-scale wind ****:	100%	40 MMTCO$_2$E/yr
	50%	20 MMTCO$_2$E/yr
	25%	10 MMTCO$_2$E/yr
Reduce electricity use for the most energy-intensive treatment technologies at National Priorities List sites by:	100%	0.4 MMTCO$_2$E/yr
	50%	0.2 MMTCO$_2$E/yr
	25%	0.1 MMTCO$_2$E/yr
Reforest percentage of qualifying former mine lands for carbon sequestration:	100%	4 MMTCO$_2$E/yr
	50%	2 MMTCO$_2$E/yr
	25%	1 MMTCO$_2$E/yr

* Most of the total technical potential scenarios presented in this table have been rounded to one significant figure. See following subsections for more detail on these estimates.

** Expected annual benefit through 2030.

*** The 100% scenario represents 141 times the projected increase in solar power between 2008 and 2030.

**** The 100% scenario represents 75% of projected increase in wind power between 2008 and 2030.

Shift 60% of expected new development to compact development patterns 79 MMTCO$_2$E per year

To date, much research has focused on the GHG emissions from transportation, and the three primary factors contributing to these emissions: vehicle fuel economy, carbon content of the fuel, and the number of VMT. In 2008, the Urban Land Institute published, *Growing Cooler: The Evidence on Urban Development and Climate Change* to describe the link between compact development patterns and the potential for reducing GHG emissions through a reduction in VMT.[155] The study presents evidence that the growth in VMT is due in large part to urban development patterns. "As a larger and larger share of the built environment has become automobile dependent, car trips and distances have increased…" For example, the study shows that the ten most sprawling metropolitan areas travel an average of 27 vehicle miles per day, while the ten least sprawling metropolitan areas travel an average of 21 vehicle miles per day.

The study draws from recent research that shows the amount of construction that will be required to meet the demands of our growing population, which is expected to reach 420 million by 2050: 89 million new or replaced homes and 190 billion square feet of new offices, institutions, stores, and other nonresidential buildings. Up to two-thirds of all development on the ground in 2050 will be built between 2007 and 2050, which provides an opportunity to select smart growth or compact development patterns over sprawling, less compact patterns.

Compact development patterns are estimated to reduce the need to drive by between 20% and 40%, compared with development at outer suburban edges. Making reasonable assumptions about growth rates, the market share of compact development, and the relationship between vehicles miles traveled and CO$_2$ emissions, the authors estimate that compact development patterns (such as those modeled on smart growth principles) could reduce total transportation related CO$_2$ emissions by 7-10% in 2050. The authors further calculate that shifting 60% of new growth to compact patterns would save 79 million tons of CO$_2$ annually by 2030.[156]

This estimate does not include additional reductions from complementary measures, such as policies designed to make drivers pay more of the full social costs of automobile use. It also does not include the energy savings from the individual buildings (e.g., compact housing uses 20% less primary energy for space heating and cooling), or the carbon sink that is protected by avoiding the development of greenfields. Further, the estimate does not take into account the long-term compounding effect, where future land use decisions would build from the compact development patterns.

Reuse percentage of qualifying EPA-tracked contaminated land for utility-scale solar

100%	2,200 MMTCO$_2$E per year
50%	1,100 MMTCO$_2$E per year
25%	540 MMTCO$_2$E per year

In order to estimate the potential of EPA-tracked sites for utility-scale solar energy generation, a dataset of EPA sites with available latitude/longitude data and acreage data was compiled. This dataset is largely based on the data reported in the *2008 OSWER Cross-Program Revitalization Measures*

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[155] Urban Land Institute. *Growing Cooler: The Evidence on Urban Development and Climate Change*. 2008. Available at: http://www.smartgrowthamerica.org/gcindex.html

[156] This estimate reflects only transportation related emissions from changes in land use patterns.

(CPRM) Report;[157] however because all CPRM sites do not have available latitude/longitude data, the acreage value of the sites mapped for this analysis is lower than reported in the CPRM and in the main text of the *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices* document.

The latitude/longitude data allowed the sites to be mapped against solar resource data layers to determine which sites were located in the areas with the highest solar resource potential. The acreage data provided the basis for estimating the amount of solar generation capacity that could be sited, as well as estimating the GHG emission benefits. The dataset of EPA tracked land with latitude/longitude and acreage data was compiled for Brownfields, Superfund, and RCRA sites as described below.

Brownfields Data: Derived from data in the Assessment Cleanup and Redevelopment Exchange (ACRES) database, queried on July 8, 2008. Dataset includes properties associated with Brownfields Grants awarded in fiscal year 2003 and beyond, where an assessment or cleanup activity has been completed and EPA Brownfields funding was expended. This includes: Assessment, Cleanup, Revolving Loan Fund, Section 128 and Targeted Brownfields Assessment grants.

RCRA Data: Includes all sites from the RCRA 2020 Universe Inventory from July 2007. Acreage information was only provided for the 2008 Baseline Inventory sites, but site latitude and longitude information was provided for all sites.

Superfund Data*:* Includes Superfund sites within the EPA OSWER Cross-Program Revitalization Measure (CPRM) universe, based on information provided by the Superfund Office on July 24, 2008, and data derived from the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS).

Additional Data Considerations

- 286 sites were identified but excluded from this analysis because latitude and longitude information was not available or the coordinates were highly suspect, as defined by mapping five miles or more from the recorded site.
- 24 U.S. territory sites with accurate latitude and longitude coordinates are excluded from this analysis because wind and solar NREL data are not available for U.S. territories.
- 29 sites located in Alaska and 22 sites in Hawaii are excluded from this analysis because transmission line data are not available for these states.
- The acreage provided in the EPA databases was used for this analysis, even if the acreage was zero.
- In order to obtain solar resource information, the site latitude and longitude point was mapped and a circular buffer was drawn around the site that was equal to the area reported for the site. The minimum and maximum renewable energy resource value found within the buffer area was collected and used for this analysis. The buffer analysis was conducted because the single latitude and longitude point available for each site may not reflect the site's overall total potential for clean and renewable energy generation. For example, a portion of a site could have a high wind power class due to being situated on a ridge line, but if the latitude and longitude recorded in EPA's databases are not along this ridgeline, the site may not meet

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[157] U.S. EPA. *OSWER Cross-Program Revitalization Measures*. March 19, 2009. Available at: http://www.epa.gov/LANDREVITALIZATION/docs/cprm_report_031709.pdf

screening criteria and may not be represented on a map. This methodology has limitations in that sites are typically not circles and latitude and longitude are not always recorded at the center of the site. However, given these limitations, this method will allow a more accurate snapshot of what energy potential may be available than a single data point.

Based on the data compiled, EPA mapped sites with an estimated total of approximately 14 million acres, as shown in Table 40. Again, this total acreage is less than that reported in the CPRM and in the main text, based on the factors described above.

Table 40: EPA Tracked Site Acreage as of Fall 2008

EPA Program	Acres
Brownfields	37,190
Non-Federal CERCLIS Proxy Sites	2,765,156
Federal CERCLIS Proxy Sites	1,014,848
Non-Federal RCRA Sites	577,885
Federal RCRA Sites	9,570,585
Total Acreage of Contaminated Sites	13,965,664

EPA used a geographic information system (GIS) in Fall 2008 to map the contaminated sites against utility-scale solar siting criteria developed by EPA in partnership with the National Renewable Energy Laboratory (NREL). The utility-scale solar photovoltaic (PV) criteria used to identify qualifying sites in this analysis include:

- Direct normal solar resource availability greater than or equal to 5 kilowatt hours (kWh)/m2/day
    - As measured by the highest resource availability within the buffer area drawn around each site's single point of latitude and longitude
- Distance to transmission lines less than or equal to 10 miles
- Acreage greater than or equal to 40 acres
- Distance to graded roads less than or equal to 25 miles

The utility-scale solar concentrating solar power (CSP) criteria used to identify qualifying sites in this analysis include:

- Direct normal solar resource availability greater than or equal to 6 kWh/m2/day
    - As measured by the highest resource availability within the buffer area drawn around each site's single point of latitude and longitude
- Distance to transmission lines less than or equal to 10 miles
- Acreage greater than or equal to 40 acres (stirling engine system); 250 acres (trough and power tower)
- Distance to graded roads less than or equal to 25 miles

Table 41: EPA Site Acreage Distribution Across
Solar Resource Potential

Solar Resource Potential - PV/CSP (kwh/m2/day)		Acreage
PV	5-5.99	942,306
	6-6.74	975,012
CSP	6.75-6.99	1,448,005
	7.00-7.24	458,806
	7.25-7.49	154,731
	7.5-7.74	584,356
	7.75+	658,951
Total		5,222,165

For each site that was identified as qualifying for utility-scale solar development, the acreage within each site's buffer area that was rated at 5 kWh/m2/day or more was extracted and counted as viable acreage for development in this analysis. Table 41 shows the acreage that qualifies for utility-scale solar. It should be noted that EPA does not determine the reuse of EPA-tracked sites. Reuse decisions for contaminated land, including EPA-tracked contaminated land, are made by individual property owners and in accordance with local and state land use regulations.

This analysis assumes that sites with a solar resource potential of 5-6.74 will be developed using PV technology, and sites with a solar resource potential greater than 6.75 will be developed using CSP parabolic trough systems. In addition, it assumes GHG emission reductions are based on a one-to-one replacement of the current U.S. fuel mix by solar. We recognize that new renewable energy projects may not actually result in a one-to-one replacement of the current U.S. fuel mix, but have used this assumption based on calculations derived from NREL reporting in order to estimate the total technical potential.[158] In addition, because the fuel source for electricity generation varies by geographic region (and therefore GHG emissions per unit of electricity capacity), we recognize that a new renewable energy electricity generation site may not "replace" the emissions associated with the current national fuel mix. Finally, this total technical potential scenario does not account for residual market effects associated with adding renewable energy capacity to U.S. electricity markets, or the possible displacement of renewable energy facilities that would have otherwise been built.

The methodology used to estimate the GHG emission reduction potential from generating electricity at 100% of the EPA-tracked acreage qualifying for utility-scale solar is summarized in Tables 42 and 43.

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[158] In practice, the additional electricity generated could result in a decrease in price, which could then induce customers to increase demand. This rebound effective could result in the use of more electricity (and thereby changing the one-to-one replacement ratio).

Table 42: Estimate of GHG Benefits from Developing 100% of EPA-tracked Contaminated Land with Solar Resource Potential of 5-6.74 as Utility-Scale Solar (PV)

Utility-Scale Solar Potential (PV) of EPA-tracked Land	Solar Resource Potential PV (kwh/m2/day)		
	5	6-6.74	Total
(A) Annual Electricity Generation (kWh) Based on 1 MW Capacity[159]	1,469,700	1,696,599	
(B) Competing Heat Rate (Btu/kWh)[160]	10,107	10,107	
(C) Annual Output (Trillion Btu)	0.015	0.017	
(D) Carbon Coefficient (MMTCB/Trillion Btu)[161]	0.01783	0.01783	
(E) Annual Carbon Displaced per MW Capacity (MMTC)	0.000265	0.000306	
(F) Carbon Dioxide Conversion Factor	3.667	3.667	
(G) Annual Emissions Displaced by 1 MW ($MMTCO_2$)[162]	0.00097	0.00112	
(H) Emissions Displaced per MWh Electricity Generated ($MMTCO_2$/MWh)	0.00000066	0.00000066	
(I) Acreage of Contaminated Land to be Reused for PV Solar[163]	942,306	975,012	1,917,317
(J) MW Capacity per Acre[164]	0.135	0.135	
(K) MW Capacity of Contaminated Land to be Reused for PV Solar	127,113	131,524	258,637
(L) Annual Electricity Generation on Contaminated Land to be Reused for PV Solar (MWh)	186,817,321	223,144,143	409,961,463
(M) Emissions Displaced by Developing Solar on Contaminated Land (MMTCO2)	123.44	147.45	271

Calculation:		
	Step 1	Annual Electricity Generation Based on 1 MW Capacity (A) x Competing Heat Rate (B) / 1,000,000,000,000 = Annual Output (C)
	Step 2	Annual Output (C) x Carbon Coefficient (D) = Annual Carbon Displaced per 1 MW Capacity (E)
	Step 3	Annual Carbon Displaced per MW Capacity (E) x Carbon Dioxide Conversion Factor (F) = Annual Emissions Displaced by 1 MW Solar Capacity (G)
	Step 4	Annual Emissions Displaced by 1 MW Solar Capacity (G) / (Annual Electricity Generation Based on 1 MW Capacity (A) / 1,000) = Emissions Displaced per MWh Electricity Generated (H)
	Step 5	Acreage of Contaminated Land to be Reused for PV Solar (I) x MW Capacity per Acre (J) = MW Capacity of Contaminated Land to be Reused for PV Solar (K)
	Step 6	Annual Electricity Generation Based on 1 MW Capacity (A) x MW Capacity of Contaminated Land to be Reused for PV Solar (K) / 1,000 = Annual Electricity Generation on Contaminated Land to be Reused for PV Solar (L)
	Step 7	Annual Emissions Displaced by 1 MW Solar Capacity (G) x MW Capacity of Contaminated Land to be Reused for PV Solar (K) = Emissions Displaced by Developing PV Solar on Contaminated Land (M)

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[159] Formula steps (A) through (E) from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Annual Electricity Generation (kWh) Based on 1 MW Capacity: U.S. Department of Energy, National Renewable Energy Laboratory. 2009. *A Performance Calculator for Grid-Connected PV Systems*. Data accessed for average annual solar radiation (kWh/m2/day) for Portland, OR (Class 3), Minneapolis, MN (Class 4) Los Angeles, CA (Class 5), and Alamosa, CO (Class 6). Available at: http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

[160] Data for steps (B) and (D) from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Heat rate from: U.S. Department of Energy, Energy Information Administration. 2004. *Annual Energy Review 2004*. Table A6. Available at: http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf

[161] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2003. *GPRA 2003 Data Call*. Appendix B, p. B-16. Available at: http://www1.eere.energy.gov/ba/pba/pdfs/fy03_gpra_data_call.pdf

[162] Emissions displaced represents only direct emissions from electricity generation

[163] Solar acreage estimate developed by EPA.

[164] U.S. Department of Energy, National Renewable Energy Laboratory. 2004. *PV FAQs.* U.S. Department of Energy, Energy Efficiency and Renewable Energy. DOE/GO-102004-1835. Available at: http://www.nrel.gov/docs/fy04osti/35097.pdf

Table 43: Estimate of GHG Benefits from Developing 100% of EPA-tracked Contaminated Land with Solar Resource Potential of 6.75+ as Utility-scale Solar (CSP)

Utility Scale Solar Potential (CSP) of EPA-tracked Land	Solar Resource Potential - CSP (kwh/m2/day)					Total
	6.75-6.99	7.00-7.24	7.25-7.49	7.50-7.74	7.75+	
(A) Acreage of Contaminated Land to be Reused for CSP Solar[165]	1,448,005	458,806	154,731	584,356	658,951	3,304,848
(B) Land Required by CSP Plant (Acres/MW) [166]	5	5	5	5	5	
(C) MW Capacity on Contaminated Land to be Reused for CSP Solar (MW)	289,601	91,761	30,946	116,871	131,790	660,970
(D) Capacity Factor[167]	40.9%	41.3%	42.7%	44.2%	45.7%	
(E) Annual Hours	8,760	8,760	8,760	8,760	8,760	
(F) Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (MWh)	1,037,593,732	331,981,001	115,754,759	452,515,552	527,598,407	2,465,443,451
(G) Emissions Displaced per MWh of Electricity Generated ($MMTCO_2E$)[168,169]	0.000001	0.000001	0.000001	0.000001	0.000001	
(H) Emissions Displaced by Developing CSP Solar on Contaminated Land ($MMTCO_2E$)	799	256	89	348	406	1,898

Calculation:		
	Step 1	Acreage of Contaminated Land to be Reused for CSP Solar (A) x Land Required by CSP Plant (B) = Total Capacity (C)
	Step 2	MW Capacity on Contaminated Land to be Reused for CSP Solar (C) x Capacity Factor (D) x Annual Hours (E) = Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (F)
	Step 3	Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (F) x Emissions Displaced per MWh of Electricity Generated (G) = Emissions Displaced by Developing CSP Solar on Contaminated Land (H)

Table 44: Estimate of GHG Benefits from Developing 100% of EPA-tracked Contaminated Land with Solar Summary

Solar Grade	5	6	7+	Total
Acreage	942,306	2,423,016	1,856,843	5,222,165
Capacity (MW)	127,113	421,125	371,369	919,607
Electricity Generation (MWh)	186,817,321	1,260,737,875	1,427,849,719	2,875,404,914
Direct Emissions Displaced ($MMTCO_2$)	123	946	1,099	2,169

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[165] Formula steps (A) through (H) derived from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Solar acreage estimate developed by EPA.

[166] Mehos, M.S. 2004. *Tackling Climate Change in the U.S. Potential Carbon Emissions Reductions from Concentrating Solar Power by 2030.* p. 83. National Renewable Energy Laboratory and David W. Kearney, Ph.D. Kearney and Associates. Available at: http://www.ases.org/climatechange/toc/04_csp.pdf

[167] Ibid. p. 87.

[168] Ibid. p. 87.

[169] Emissions displaced represents only direct emissions from electricity generation.

NOTE: The estimated amount of electricity generation from developing 100% of qualifying EPA-tracked land for utility-scale solar is over 2,875 billion kWh. EIA projects that between 2008 and 2030, total generation from solar resources will increase by over 20 billion kWh.[170] Therefore, 100% of EPA-tracked land for solar could support approximately 141 times the projected growth in electricity generated from solar resources by 2030.

To estimate the GHG emission reduction potential from siting utility-scale solar on 50% of the EPA-tracked acreage, it was assumed that 50% of the acreage in each solar resource potential category would be available for reuse, as summarized in Table 45.

Table 45: EPA Site Acreage Distribution Across Solar Resource Potential

Solar Resource Potential - PV/CSP (kwh/m2/day)		Total Acreage	50% of Acreage
PV	5-5.99	942,306	471,153
	6-6.74	975,012	487,506
CSP	6.75-6.99	1,448,005	724,003
	7.00-7.24	458,806	229,403
	7.25-7.49	154,731	77,365
	7.5-7.74	584,356	292,178
	7.75+	658,951	329,476
Total		5,222,165	2,611,083

The same methodology was used to estimate the GHG emission reduction potential from siting utility-scale solar, assuming that 50% of the EPA-tracked acreage qualifying for utility-scale solar could be reused, as shown in Tables 46 and 47, and summarized in Table 48.

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[170] U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

Table 46: Estimate of GHG Benefits from Developing 50% of EPA-tracked Contaminated Land with Solar Resource Potential of 5-6.74 as Utility-Scale Solar (PV)

Utility-Scale Solar Potential (PV) of EPA-tracked Land	Solar Resource Potential PV (kwh/m2/day)		
	5	6-6.74	Total
(A) Annual Electricity Generation (kWh) Based on 1 MW Capacity[171]	1,469,700	1,696,599	
(B) Competing Heat Rate (Btu/kWh)[172]	10,107	10,107	
(C) Annual Output (Trillion Btu)	0.015	0.017	
(D) Carbon Coefficient (MMTCB/Trillion Btu)[173]	0.01783	0.01783	
(E) Annual Carbon Displaced per MW Capacity (MMTC)	0.000265	0.000306	
(F) Carbon Dioxide Conversion Factor	3.667	3.667	
(G) Annual Emissions Displaced by 1 MW ($MMTCO_2$)[174]	0.00097	0.00112	
(H) Emissions Displaced per MWh Electricity Generated ($MMTCO_2$/MWh)	0.00000066	0.00000066	
(I) Acreage of Contaminated Land to be Reused for PV Solar[175]	471,153	487,506	958,659
(J) MW Capacity per Acre[176]	0.135	0.135	
(K) MW Capacity of Contaminated Land to be Reused for PV Solar	63,556	65,762	129,318
(L) Annual Electricity Generation on Contaminated Land to be Reused for PV Solar (MWh)	93,408,660	111,572,071	204,980,732
(M) Emissions Displaced by Developing Solar on Contaminated Land ($MMTCO_2$)	61.72	73.72	135

Calculation:	Step 1	Annual Electricity Generation Based on 1 MW Capacity (A) x Competing Heat Rate (B) / 1,000,000,000,000 = Annual Output (C)
	Step 2	Annual Output (C) x Carbon Coefficient (D) = Annual Carbon Displaced per 1 MW Capacity (E)
	Step 3	Annual Carbon Displaced per MW Capacity (E) x Carbon Dioxide Conversion Factor (F) = Annual Emissions Displaced by 1 MW Solar Capacity (G)
	Step 4	Annual Emissions Displaced by 1 MW Solar Capacity (G) / (Annual Electricity Generation Based on 1 MW Capacity (A) / 1,000) = Emissions Displaced per MWh Electricity Generated (H)
	Step 5	Acreage of Contaminated Land to be Reused for PV Solar (I) x MW Capacity per Acre (J) = MW Capacity of Contaminated Land to be Reused for PV Solar (K)
	Step 6	Annual Electricity Generation Based on 1 MW Capacity (A) x MW Capacity of Contaminated Land to be Reused for PV Solar (K) / 1,000 = Annual Electricity Generation on Contaminated Land to be Reused for PV Solar (L)
	Step 7	Annual Emissions Displaced by 1 MW Solar Capacity (G) x MW Capacity of Contaminated Land to be Reused for PV Solar (K) = Emissions Displaced by Developing PV Solar on Contaminated Land (M)

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[171] Formula steps (A) through (E) from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Annual Electricity Generation (kWh) Based on 1 MW Capacity: U.S. Department of Energy, National Renewable Energy Laboratory. 2009. *A Performance Calculator for Grid-Connected PV Systems*. Data accessed for average annual solar radiation (kWh/m2/day) for Portland, OR (Class 3), Minneapolis, MN (Class 4) Los Angeles, CA (Class 5), and Alamosa, CO (Class 6). Available at: http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

[172] Data for steps (B) and (D) from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Heat rate from: U.S. Department of Energy, Energy Information Administration. 2004. *Annual Energy Review 2004*. Table A6. Available at: http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf

[173] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2003. *GPRA 2003 Data Call*. Appendix B, p. B-16. Available at: http://www1.eere.energy.gov/ba/pba/pdfs/fy03_gpra_data_call.pdf

[174] Emissions displaced represents only direct emissions from electricity generation

[175] Solar acreage estimate developed by EPA.

[176] U.S. Department of Energy, National Renewable Energy Laboratory. 2004. *PV FAQs.* U.S. Department of Energy, Energy Efficiency and Renewable Energy. DOE/GO-102004-1835. Available at: http://www.nrel.gov/docs/fy04osti/35097.pdf

Table 47: Estimate of GHG Benefits from Developing 50% of EPA-tracked Contaminated Land with Solar Resource Potential of 6.75+ as Utility-scale Solar (CSP)

Utility Scale Solar Potential (CSP) of EPA-tracked Land	Solar Resource Potential - CSP (kwh/m2/day)					Total
	6.75-6.99	7.00-7.24	7.25-7.49	7.50-7.74	7.75+	
(A) Acreage of Contaminated Land to be Reused for CSP Solar[177]	724,002	229,403	77,365	292,178	329,476	1,652,424
(B) Land Required by CSP Plant (Acres/MW) [178]	5	5	5	5	5	
(C) MW Capacity on Contaminated Land to be Reused for CSP Solar (MW)	144,800	45,881	15,473	58,436	65,895	330,485
(D) Capacity Factor[179]	40.9%	41.3%	42.7%	44.2%	45.7%	
(E) Annual Hours	8,760	8,760	8,760	8,760	8,760	
(F) Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (MWh)	518,796,866	165,990,501	57,877,379	226,257,776	263,799,204	1,232,721,726
(G) Emissions Displaced per MWh of Electricity Generated (MMTCO$_2$E)[180, 181]	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
(H) Emissions Displaced by Developing CSP Solar on Contaminated Land (MMTCO$_2$E)	399	128	45	174	203	949

Calculation:

Calculation:	Step 1	Acreage of Contaminated Land to be Reused for CSP Solar (A) x Land Required by CSP Plant (B) = Total Capacity (C)
	Step 2	MW Capacity on Contaminated Land to be Reused for CSP Solar (C) x Capacity Factor (D) x Annual Hours (E) = Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (F)
	Step 3	Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (F) x Emissions Displaced per MWh of Electricity Generated (G) = Emissions Displaced by Developing CSP Solar on Contaminated Land (H)

Table 48: Estimate of GHG Benefits from Developing 50% of EPA-tracked Contaminated Land with Solar Summary

Solar Resource Potential	5	6	7+	Total
Acreage	471,153	1,211,508	928,422	2,611,083
Capacity (MW)	63,556	210,563	185,684	459,803
Electricity Generation (MWh)	93,408,660	630,368,937	713,924,860	1,437,702,457
Direct Emissions Displaced (MMTCO2)	62	473	550	1,085

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[177] Formula steps (A) through (H) derived from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Solar acreage estimate developed by EPA.

[178] Mehos, M.S. 2004. *Tackling Climate Change in the U.S. Potential Carbon Emissions Reductions from Concentrating Solar Power by 2030.* p. 83. National Renewable Energy Laboratory and David W. Kearney, Ph.D. Kearney and Associates. Available at: http://www.ases.org/climatechange/toc/04_csp.pdf

[179] Ibid. p. 87.

[180] Ibid. p. 87.

[181] Emissions displaced represents only direct emissions from electricity generation.

NOTE: The estimated amount of electricity generation from developing 50% of qualifying EPA-tracked land for utility-scale solar is over 1,437 billion kWh. EIA projects that between 2008 and 2030, total generation from solar resources will increase by over 20 billion kWh.[182] Therefore, 50% of EPA-tracked land could support approximately 70 times the projected growth in electricity generated from solar resources by 2030.

To estimate the GHG emission reduction potential from siting utility-scale solar on 25% of the EPA-tracked sites, it was assumed that 25% of the acreage in each solar resource potential category would be available for reuse, as summarized in Table 49.

Table 49: EPA Site Acreage Distribution Across Solar Resource Potential

Solar Resource Potential - PV/CSP (kwh/m2/day)		Total Acreage	25% of Acreage
PV	5-5.99	942,306	235,577
	6-6.74	975,012	243,753
CSP	6.75-6.99	1,448,005	362,001
	7.00-7.24	458,806	114,701
	7.25-7.49	154,731	38,683
	7.5-7.74	584,356	146,089
	7.75+	658,951	164,738
Total		5,222,165	1,305,542

The same methodology was used to estimate the GHG emission reduction potential from siting utility-scale solar, assuming that 25% of the EPA-tracked acreage qualifying for utility-scale solar could be reused, as shown in Tables 50 and 51, and summarized in Table 52.

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[182] U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

Table 50: Estimate of GHG Benefits from Developing 25% of EPA-tracked Contaminated Land with Solar Resource Potential of 5-6.74 as Utility-Scale Solar (PV)

Utility-Scale Solar Potential (PV) of EPA-tracked Land	Solar Resource Potential PV (kwh/m2/day)		
	5	6-6.74	Total
(A) Annual Electricity Generation (kWh) Based on 1 MW Capacity[183]	1,469,700	1,696,599	
(B) Competing Heat Rate (Btu/kWh)[184]	10,107	10,107	
(C) Annual Output (Trillion Btu)	0.015	0.017	
(D) Carbon Coefficient (MMTCB/Trillion Btu)[185]	0.01783	0.01783	
(E) Annual Carbon Displaced per MW Capacity (MMTC)	0.000265	0.000306	
(F) Carbon Dioxide Conversion Factor	3.667	3.667	
(G) Annual Emissions Displaced by 1 MW ($MMTCO_2$)[186]	0.00097	0.00112	
(H) Emissions Displaced per MWh Electricity Generated ($MMTCO_2$/MWh)	0.00000066	0.00000066	
(I) Acreage of Contaminated Land to be Reused for PV Solar[187]	235,576	243,753	479,329
(J) MW Capacity per Acre[188]	0.135	0.135	
(K) MW Capacity of Contaminated Land to be Reused for PV Solar	31,778	32,881	64,659
(L) Annual Electricity Generation on Contaminated Land to be Reused for PV Solar (MWh)	46,704,330	55,786,036	102,490,366
(M) Emissions Displaced by Developing Solar on Contaminated Land ($MMTCO_2$)	30.86	36.86	68

Calculation:	Step 1	Annual Electricity Generation Based on 1 MW Capacity (A) x Competing Heat Rate (B) / 1,000,000,000,000 = Annual Output (C)
	Step 2	Annual Output (C) x Carbon Coefficient (D) = Annual Carbon Displaced per 1 MW Capacity (E)
	Step 3	Annual Carbon Displaced per MW Capacity (E) x Carbon Dioxide Conversion Factor (F) = Annual Emissions Displaced by 1 MW Solar Capacity (G)
	Step 4	Annual Emissions Displaced by 1 MW Solar Capacity (G) / (Annual Electricity Generation Based on 1 MW Capacity (A) / 1,000) = Emissions Displaced per MWh Electricity Generated (H)
	Step 5	Acreage of Contaminated Land to be Reused for PV Solar (I) x MW Capacity per Acre (J) = MW Capacity of Contaminated Land to be Reused for PV Solar (K)
	Step 6	Annual Electricity Generation Based on 1 MW Capacity (A) x MW Capacity of Contaminated Land to be Reused for PV Solar (K) / 1,000 = Annual Electricity Generation on Contaminated Land to be Reused for PV Solar (L)
	Step 7	Annual Emissions Displaced by 1 MW Solar Capacity (G) x MW Capacity of Contaminated Land to be Reused for PV Solar (K) = Emissions Displaced by Developing PV Solar on Contaminated Land (M)

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[183] Formula steps (A) through (E) from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Annual Electricity Generation (kWh) Based on 1 MW Capacity: U.S. Department of Energy, National Renewable Energy Laboratory. 2009. *A Performance Calculator for Grid-Connected PV Systems*. Data accessed for average annual solar radiation (kWh/m2/day) for Portland, OR (Class 3), Minneapolis, MN (Class 4) Los Angeles, CA (Class 5), and Alamosa, CO (Class 6). Available at: http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

[184] Data for steps (B) and (D) from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Heat rate from: U.S. Department of Energy, Energy Information Administration. 2004. *Annual Energy Review* 2004. Table A6. Available at: http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf

[185] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2003. *GPRA 2003 Data Call*. Appendix B, p. B-16. Available at: http://www1.eere.energy.gov/ba/pba/pdfs/fy03_gpra_data_call.pdf

[186] Emissions displaced represents only direct emissions from electricity generation.

[187] Solar acreage estimate developed by EPA.

[188] U.S. Department of Energy, National Renewable Energy Laboratory. 2004. PV FAQs. U.S. Department of Energy, Energy Efficiency and Renewable Energy. DOE/GO-102004-1835. Available at: http://www.nrel.gov/docs/fy04osti/35097.pdf

Table 51: Estimate of GHG Benefits from Developing 25% of EPA-tracked Contaminated Land with Solar Resource Potential of 6.75+ as Utility-scale Solar (CSP)

Utility Scale Solar Potential (CSP) of EPA-tracked Land	Solar Resource Potential - CSP (kwh/m2/day)					Total
	6.75-6.99	7.00-7.24	7.25-7.49	7.50-7.74	7.75+	
(A) Acreage of Contaminated Land to be Reused for CSP Solar[189]	362,001	114,701	38,683	146,089	164,738	826,212
(B) Land Required by CSP Plant (Acres/MW) [190]	5	5	5	5	5	
(C) MW Capacity on Contaminated Land to be Reused for CSP Solar (MW)	72,400	22,940	7,737	29,218	32,948	165,242
(D) Capacity Factor[191]	40.9%	41.3%	42.7%	44.2%	45.7%	
(E) Annual Hours	8,760	8,760	8,760	8,760	8,760	
(F) Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (MWh)	259,398,433	82,995,250	28,938,690	113,128,888	131,899,602	616,360,863
(G) Emissions Displaced per MWh of Electricity Generated (MMTCO$_2$E)[192,193]	0.000001	0.000001	0.000001	0.000001	0.000001	0.000001
(H) Emissions Displaced by Developing CSP Solar on Contaminated Land (MMTCO$_2$E)	200	64	22	87	102	475

Calculation:	Step 1	Acreage of Contaminated Land to be Reused for CSP Solar (A) x Land Required by CSP Plant (B) = Total Capacity (C)
	Step 2	MW Capacity on Contaminated Land to be Reused for CSP Solar (C) x Capacity Factor (D) x Annual Hours (E) = Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (F)
	Step 3	Annual Electricity Generation on Contaminated Land to be Reused for CSP Solar (F) x Emissions Displaced per MWh of Electricity Generated (G) = Emissions Displaced by Developing CSP Solar on Contaminated Land (H)

Table 52: Estimate of GHG Benefits from Developing 25% of EPA-tracked Contaminated Land with Solar Summary

Solar Grade	5	6	7+	Total
Acreage	235,576	605,754	464,211	1,305,541
Capacity (MW)	31,778	105,281	92,842	229,902
Electricity Generation (MWh)	46,704,330	315,184,469	356,962,430	718,851,229
Direct Emissions Displaced (MMTCO$_2$)	31	237	275	542

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[189] Formula steps (A) through (H) derived from U.S. Department of Energy, National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book, Fourth Edition*. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Solar acreage estimate developed by EPA.

[190] Mehos, M.S. 2004. *Tackling Climate Change in the U.S. Potential Carbon Emissions Reductions from Concentrating Solar Power by 2030.* p. 83. National Renewable Energy Laboratory and David W. Kearney, Ph.D. Kearney and Associates. Available at: http://www.ases.org/climatechange/toc/04_csp.pdf

[191] Ibid. p. 87.

[192] Ibid. p. 87.

[193] Emissions displaced represents only direct emissions from electricity generation.

NOTE: The estimated amount of electricity generation from developing 25% of qualifying EPA-tracked land for utility-scale solar is over 718 billion kWh. EIA projects that between 2008 and 2030, total generation from solar resources will increase by over 20 billion kWh.[194] Therefore, 25% of EPA-tracked land could support approximately 35 times the projected growth in electricity generated from solar resources by 2030.

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 2,200 MMTCO$_2$E (100% scenario), 1,100 MMTCO$_2$E (50% scenario), and 540 MMTCO$_2$E (25% scenario).

Reuse percentage of qualifying EPA-tracked contaminated land for community and utility-scale wind

100%	40 MMTCO$_2$E per year
50%	20 MMTCO$_2$E per year
25%	10 MMTCO$_2$E per year

In order to estimate the potential of EPA-tracked sites for utility- and community-scale wind energy generation, we compiled a dataset of EPA sites that has available latitude/longitude data and acreage data as described in the preceding section.

We used GIS in Fall 2008 to map the contaminated sites against utility-scale solar siting criteria developed by EPA in partnership with the NREL. The utility-scale wind criteria used to identify qualifying sites in this analysis includes:

- Wind class, measured at 50 meters above ground greater than or equal to 4
  - As measured by the highest resource availability within the buffer area drawn around each site's single point of latitude and longitude
- Distance to transmission lines less than or equal to 10 miles
- Acreage greater than or equal to 2,000
- Distance to graded roads less than or equal to 25 miles

The community-scale wind criteria used to identify qualifying sites in this analysis includes:

- Wind class, measured at 50 meters above ground greater than or equal to 3
  - As measured by the highest resource availability within the buffer area drawn around each site's single point of latitude and longitude
- Acreage of 100 – 1,999
- Distance to graded roads less than or equal to 25 miles

For each site that was identified as qualifying for utility-scale or community-scale wind development, the acreage within each site's buffer area that was rated at 4 or more, or 3 or more, respectively was extracted and counted as viable acreage for development in this analysis. Table 53 shows the acreage that qualifies for utility- and community-scale wind. It should be noted that EPA does not determine the reuse of EPA-tracked sites. Reuse decisions for contaminated land, including EPA-tracked contaminated land, are made by individual property owners and in accordance with local and state land use regulations.

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[194] U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

Table 53: EPA Site Acreage Distribution Across Wind Class

Wind Class (measured at 50 meters above ground)	Utility-Scale Acreage	Community-Scale Acreage	Total Acreage
3	-	45,350	45,350
4	194,595	9,271	203,865
5	260,421	1,042	261,464
6	44,560	155	44,715
7	23,273	730	24,003
Total	522,850	56,548	579,398

Table 54 shows the steps used to calculate the GHG emission benefit of generating electricity at 100% of the EPA-tracked acreage qualifying for utility-scale and community-scale wind in lieu of the current U.S. fuel mix. We recognize that new renewable energy projects may not actually result in a one-to-one replacement of the current U.S. fuel mix, but have used this assumption based on calculations used by NREL in order to estimate the total technical potential.[195] In addition, because the fuel source for electricity generation varies by geographic region (and therefore GHG emissions per unit of electricity capacity), we recognize that a new renewable energy electricity generation site may not "replace" the emissions associated with the current national fuel mix. Finally, this total technical potential scenario does not account for residual market effects associated with adding renewable energy capacity to U.S. electricity markets, or the possible displacement of renewable energy facilities that would have otherwise been built.

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[195] In practice, the additional electricity generated could result in a decrease in price, which could then induce customers to increase demand. This rebound effective could result in the use of more electricity (and thereby changing the one-to-one replacement ratio).

Table 54: Estimate of GHG Benefits from Developing 100% of EPA-tracked Contaminated Land as Utility- and Community-scale Wind

	Wind Class 3	Wind Class 4	Wind Class 5	Wind Class 6	Wind Class 7	Total
(A) Total U.S. Capacity 2008 (kW)[196,197]	24,885,767	24,885,767	24,885,767	24,885,767	24,885,767	
(B) Capacity Factor[198]	32%	36%	40%	44%	47%	
(C) Annual Hours	8,760	8,760	8,760	8,760	8,760	
(D) Annual U.S. Electricity Generation (kWh)	69,759,782,007	78,479,754,758	87,199,727,509	95,919,700,259	102,459,679,823	
(E) Competing Heat Rate (Btu/kWh)[199]	10,107	10,107	10,107	10,107	10,107	
(F) Annual Output (Trillion Btu)	705	793	881	969	1,036	
(G) Carbon Coefficient (MMTCB/Trillion Btu)[200]	0.01783	0.01783	0.01783	0.01783	0.01783	
(H) Annual U.S. Carbon Displaced (MMTC)	12.571	14.143	15.714	17.285	18.464	
(I) Carbon Dioxide Conversion Factor[201]	3.667	3.667	3.667	3.667	3.667	
(J) Annual U.S. Emissions Displaced (MMTCO$_2$)[202]	46.095	51.856	57.618	63.380	67.701	
(K) Emissions Displaced per MW Capacity (MMTCO$_2$/MW)	0.001852248	0.002083779	0.002315310	0.002546841	0.002720489	
(L) Emissions Displaced per MWh Electricity Generated (MMTCO$_2$/MWh)	0.000000661	0.000000661	0.000000661	0.000000661	0.000000661	
(M) Acreage of Contaminated Land to be Reused for Wind[203]	45,350	203,865	261,464	44,715	24,003	579,398
(N) MW Capacity per Acre[204]	0.030	0.030	0.030	0.030	0.030	
(O) Capacity on Contaminated Land to be Reused for Wind (MW)	1,360	6,116	7,844	1,341	720	17,382
(P) Annual Electricity Generation on Contaminated Land to be Reused for Wind (MWh)	3,813,751	19,287,284	27,485,070	5,170,531	2,964,781	58,721,417
(Q) Emissions Displaced by Developing Wind on Contaminated Land (MMTCO$_2$E)	2.52	12.74	18.16	3.42	1.96	39

Calculation:		
	Step 1	Total U.S. Capacity 2008 (A) x Capacity Factor (B) x Annual Hours (C) = Annual U.S. Electricity Generation (D)
	Step 2	Annual U.S. Electricity Generation (D) x Competing Heat Rate (E) = Annual Output (F)
	Step 3	Annual Output (F) x Carbon Coefficient (G) = Annual U.S. Carbon Displaced (H)
	Step 4	Annual U.S. Carbon Displaced (H) x Carbon Dioxide Conversion Factor (I) = Annual U.S. Emissions Displaced (J)
	Step 5	Annual U.S. Emissions Displaced (J) / (Total U.S. Capacity (A) / 1,000) = Emissions Displaced per MW Capacity (K)
	Step 6	Annual U.S. Emissions Displaced (J) / (Annual U.S. Electricity Generation (D) / 1,000) = Emissions Displaced per MWh Electricity Generated (L)
	Step 7	Acreage of Contaminated Land to be Reused for Wind (M) x MW Capacity per Acre (N) = Capacity on Contaminated Land to be Reused for Wind (O)
	Step 8	Capacity on Contaminated Land to be Reused for Wind (O) * Capacity Factor (B) * Annual Hours (C) = Annual Electricity Generation on Contaminated Land to be Reused for Wind (P)
	Step 9	Emissions Displaced per MWh Electricity Generated (L) x Annual Electricity Generation on Contaminated Land to be Reused for Wind (P) = Emissions Displaced by Developing Wind on Contaminated Land (Q)

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[196] Formula steps (A) through (H) from National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book*, Fourth Edition. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Data for steps (A) through (H) also from Table 12.1, unless otherwise noted.

[197] Projected values for the year 2009 from U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

[198] Black and Veatch draft capacity factors to be publicly released by NREL in 2008.

[199] U.S. Department of Energy, Energy Information Administration. 2004. *Annual Energy Review 2004*. Table A6. Available at: http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf

[200] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2003. *GPRA 2003 Data Call*. Appendix B, p. B-16. Available at: http://www1.eere.energy.gov/ba/pba/pdfs/fy03_gpra_data_call.pdf

[201] U.S. EPA. 2009. Clean Energy: Calculations and References. Available at: http://www.epa.gov/solar/energy-resources/refs.html

[202] Emissions displaced represents only direct emissions from electricity generation.

[203] Wind acreage estimate developed by EPA.

[204] EPA interview with U.S. Department of Energy, National Renewable Energy Laboratory to identify acreage required to for 5-10 MW of capacity. February 2008.

NOTE: The estimated amount of electricity generation from developing 100% of qualifying EPA-tracked land for utility- or community-scale wind is over 58 billion kWh. EIA projects that between 2008 and 2030, total generation from wind resources will increase by over 77 billion kWh.[205] Therefore, 100% of EPA-tracked land could support approximately 75% of the projected growth in electricity generated from wind resources by 2030.

To estimate the GHG emission reduction potential from siting utility-scale and community-scale wind on 50% of the EPA-tracked sites, it was assumed that 50% of the acreage in each wind class would be available for reuse, as summarized in Table 55.

Table 55: EPA Site Acreage Distribution Across Wind Class

Wind Class (measured at 50 meters above ground)	Total Acreage	50% of Acreage
3	45,350	22,675
4	203,865	101,933
5	261,464	130,732
6	44,715	22,358
7	24,003	12,002
Total	579,398	289,699

The same methodology was used to estimate the GHG emission reduction potential from siting utility-scale and community-scale wind, assuming that 50% of the EPA-tracked acreage qualifying for utility-scale and community-scale wind could be reused, as shown in Table 56.

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[205] U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

Table 56: Estimate of GHG Benefits from Developing 50% of EPA-tracked Contaminated Land as Utility- and Community-scale Wind

	Wind Class 3	Wind Class 4	Wind Class 5	Wind Class 6	Wind Class 7	Total
(A) Total U.S. Capacity 2008 (kW)[206,207]	24,885,767	24,885,767	24,885,767	24,885,767	24,885,767	
(B) Capacity Factor[208]	32%	36%	40%	44%	47%	
(C) Annual Hours	8,760	8,760	8,760	8,760	8,760	
(D) Annual U.S. Electricity Generation (kWh)	69,759,782,007	78,479,754,758	87,199,727,509	95,919,700,259	102,459,679,823	
(E) Competing Heat Rate (Btu/kWh)[209]	10,107	10,107	10,107	10,107	10,107	
(F) Annual Output (Trillion Btu)	705	793	881	969	1,036	
(G) Carbon Coefficient (MMTCB/Trillion Btu)[210]	0.01783	0.01783	0.01783	0.01783	0.01783	
(H) Annual U.S. Carbon Displaced (MMTC)	12.571	14.143	15.714	17.285	18.464	
(I) Carbon Dioxide Conversion Factor[211]	3.667	3.667	3.667	3.667	3.667	
(J) Annual U.S. Emissions Displaced (MMTCO$_2$)[212]	46.095	51.856	57.618	63.380	67.701	
(K) Emissions Displaced per MW Capacity (MMTCO$_2$/MW)	0.001852248	0.002083779	0.002315310	0.002546841	0.002720489	
(L) Emissions Displaced per MWh Electricity Generated (MMTCO$_2$/MWh)	0.000000661	0.000000661	0.000000661	0.000000661	0.000000661	
(M) Acreage of Contaminated Land to be Reused for Wind[213]	22,675	101,933	130,732	22,358	12,002	289,699
(N) MW Capacity per Acre[214]	0.030	0.030	0.030	0.030	0.030	
(O) Capacity on Contaminated Land to be Reused for Wind (MW)	680	3,058	3,922	671	360	8,691
(P) Annual Electricity Generation on Contaminated Land to be Reused for Wind (MWh)	1,906,875	9,643,642	13,742,535	2,585,266	1,482,390	29,360,709
(Q) Emissions Displaced by Developing Wind on Contaminated Land (MMTCO$_2$E)	1.26	6.37	9.08	1.71	0.98	19

Calculation:	Step 1	Total U.S. Capacity 2008 (A) x Capacity Factor (B) x Annual Hours (C) = Annual U.S. Electricity Generation (D)
	Step 2	Annual U.S. Electricity Generation (D) x Competing Heat Rate (E) = Annual Output (F)
	Step 3	Annual Output (F) x Carbon Coefficient (G) = Annual U.S. Carbon Displaced (H)
	Step 4	Annual U.S. Carbon Displaced (H) x Carbon Dioxide Conversion Factor (I) = Annual U.S. Emissions Displaced (J)
	Step 5	Annual U.S. Emissions Displaced (J) / (Total U.S. Capacity (A) / 1,000) = Emissions Displaced per MW Capacity (K)
	Step 6	Annual U.S. Emissions Displaced (J) / (Annual U.S. Electricity Generation (D) / 1,000) = Emissions Displaced per MWh Electricity Generated (L)
	Step 7	Acreage of Contaminated Land to be Reused for Wind (M) x MW Capacity per Acre (N) = Capacity on Contaminated Land to be Reused for Wind (O)
	Step 8	Capacity on Contaminated Land to be Reused for Wind (O) * Capacity Factor (B) * Annual Hours (C) = Annual Electricity Generation on Contaminated Land to be Reused for Wind (P)
	Step 9	Emissions Displaced per MWh Electricity Generated (L) x Annual Electricity Generation on Contaminated Land to be Reused for Wind (P) = Emissions Displaced by Developing Wind on Contaminated Land (Q)

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[206] Formula steps (A) through (H) from National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book*, Fourth Edition. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Data for steps (A) through (H) also from Table 12.1, unless otherwise noted.

[207] Projected values for the year 2009 from U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

[208] Black and Veatch draft capacity factors to be publicly released by NREL in 2008.

[209] U.S. Department of Energy, Energy Information Administration. 2004. *Annual Energy Review 2004*. Table A6. Available at: http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf

[210] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2003. *GPRA 2003 Data Call*. Appendix B, p. B-16. Available at: http://www1.eere.energy.gov/ba/pba/pdfs/fy03_gpra_data_call.pdf

[211] U.S. EPA. 2009. Clean Energy: Calculations and References. Available at: http://www.epa.gov/solar/energy-resources/refs.html

[212] Emissions displaced represents only direct emissions from electricity generation.

[213] Wind acreage estimate developed by EPA.

[214] EPA interview with U.S. Department of Energy, National Renewable Energy Laboratory to identify acreage required to for 5-10 MW of capacity. February 2008.

NOTE: The estimated amount of electricity generation from developing 50% of qualifying EPA-tracked land for utility- or community-scale wind is over 29 billion kWh. EIA projects that between 2008 and 2030, total generation from wind resources will increase by over 77 billion kWh.[215] Therefore, 50% of EPA-tracked land could support approximately 38% of the projected growth in electricity generated from wind resources by 2030.

To estimate the GHG emission reduction potential from siting utility-scale and community-scale wind on 25% of the EPA-tracked sites, it was assumed that 25% of the acreage in each wind class would be available for reuse, as summarized in Table 57.

Table 57: EPA Site Acreage Distribution Across Wind Class

Wind Class (measured at 50 meters above ground)	Total Acreage	25% of Acreage
3	45,350	11,337
4	203,865	50,966
5	261,464	65,366
6	44,715	11,179
7	24,003	6,001
Total	579,398	144,849

The same methodology was used to estimate the GHG emission reduction potential from siting utility-scale and community-scale wind, assuming that 25% of the EPA-tracked acreage qualifying for utility-scale and community-scale wind could be reused, as shown in Table 58.

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[215] U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

Table 58: Estimate of GHG Benefits from Developing 50% of EPA-tracked Contaminated Land as Utility- and Community-scale Wind

	Wind Class 3	Wind Class 4	Wind Class 5	Wind Class 6	Wind Class 7	Total
(A) Total U.S. Capacity 2008 (kW)[216,217]	24,885,767	24,885,767	24,885,767	24,885,767	24,885,767	
(B) Capacity Factor[218]	32%	36%	40%	44%	47%	
(C) Annual Hours	8,760	8,760	8,760	8,760	8,760	
(D) Annual U.S. Electricity Generation (kWh)	69,759,782,007	78,479,754,758	87,199,727,509	95,919,700,259	102,459,679,823	
(E) Competing Heat Rate (Btu/kWh)[219]	10,107	10,107	10,107	10,107	10,107	
(F) Annual Output (Trillion Btu)	705	793	881	969	1,036	
(G) Carbon Coefficient (MMTCB/Trillion Btu)[220]	0.01783	0.01783	0.01783	0.01783	0.01783	
(H) Annual U.S. Carbon Displaced (MMTC)	12.571	14.143	15.714	17.285	18.464	
(I) Carbon Dioxide Conversion Factor[221]	3.667	3.667	3.667	3.667	3.667	
(J) Annual U.S. Emissions Displaced ($MMTCO_2$)[222]	46.095	51.856	57.618	63.380	67.701	
(K) Emissions Displaced per MW Capacity ($MMTCO_2$/MW)	0.001852248	0.002083779	0.002315310	0.002546841	0.002720489	
(L) Emissions Displaced per MWh Electricity Generated ($MMTCO_2$/MWh)	0.000000661	0.000000661	0.000000661	0.000000661	0.000000661	
(M) Acreage of Contaminated Land to be Reused for Wind[223]	11,337	50,966	65,366	11,179	6,001	144,849
(N) MW Capacity per Acre[224]	0.030	0.030	0.030	0.030	0.030	
(O) Capacity on Contaminated Land to be Reused for Wind (MW)	340	1,529	1,961	335	180	4,345
(P) Annual Electricity Generation on Contaminated Land to be Reused for Wind (MWh)	953,438	4,821,821	6,871,268	1,292,633	741,195	14,680,354
(Q) Emissions Displaced by Developing Wind on Contaminated Land ($MMTCO_2E$)	0.63	3.19	4.54	0.85	0.49	10

Calculation:	Step 1	Total U.S. Capacity 2008 (A) x Capacity Factor (B) x Annual Hours (C) = Annual U.S. Electricity Generation (D)
	Step 2	Annual U.S. Electricity Generation (D) x Competing Heat Rate (E) = Annual Output (F)
	Step 3	Annual Output (F) x Carbon Coefficient (G) = Annual U.S. Carbon Displaced (H)
	Step 4	Annual U.S. Carbon Displaced (H) x Carbon Dioxide Conversion Factor (I) = Annual U.S. Emissions Displaced (J)
	Step 5	Annual U.S. Emissions Displaced (J) / (Total U.S. Capacity (A) / 1,000) = Emissions Displaced per MW Capacity (K)
	Step 6	Annual U.S. Emissions Displaced (J) / (Annual U.S. Electricity Generation (D) / 1,000) = Emissions Displaced per MWh Electricity Generated (L)
	Step 7	Acreage of Contaminated Land to be Reused for Wind (M) x MW Capacity per Acre (N) = Capacity on Contaminated Land to be Reused for Wind (O)
	Step 8	Capacity on Contaminated Land to be Reused for Wind (O) * Capacity Factor (B) * Annual Hours (C) = Annual Electricity Generation on Contaminated Land to be Reused for Wind (P)
	Step 9	Emissions Displaced per MWh Electricity Generated (L) x Annual Electricity Generation on Contaminated Land to be Reused for Wind (P) = Emissions Displaced by Developing Wind on Contaminated Land (Q)

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[216] Formula steps (A) through (H) from National Renewable Energy Laboratory. 2006. *Power Technologies Energy Data Book*, Fourth Edition. Table 12.1. Available at: http://www.nrel.gov/analysis/power_databook/. Data for steps (A) through (H) also from Table 12.1, unless otherwise noted.

[217] Projected values for the year 2009 from U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

[218] Black and Veatch draft capacity factors to be publicly released by NREL in 2008.

[219] U.S. Department of Energy, Energy Information Administration. 2004. *Annual Energy Review 2004*. Table A6. Available at: http://tonto.eia.doe.gov/FTPROOT/multifuel/038404.pdf

[220] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2003. *GPRA 2003 Data Call*. Appendix B, p. B-16. Available at: http://www1.eere.energy.gov/ba/pba/pdfs/fy03_gpra_data_call.pdf

[221] U.S. EPA. 2009. Clean Energy: Calculations and References. Available at: http://www.epa.gov/solar/energy-resources/refs.html

[222] Emissions displaced represents only direct emissions from electricity generation.

[223] Wind acreage estimate developed by EPA.

[224] EPA interview with U.S. Department of Energy, National Renewable Energy Laboratory to identify acreage required to for 5-10 MW of capacity. February 2008.

NOTE: The estimated amount of electricity generation from developing 25% of qualifying EPA-tracked land for utility- or community-scale wind is over 14 billion kWh. EIA projects that between 2008 and 2030, total generation from wind resources will increase by over 77 billion kWh.[225] Therefore, 25% of EPA-tracked land could support approximately 19% of the projected growth in electricity generated from wind resources by 2030.

In the main text and summary tables, the estimated GHG emission benefit associated with this total technical potential scenario is rounded to 40 MMTCO$_2$E (100% scenario), 20 MMTCO$_2$E (50% scenario), and 10 MMTCO$_2$E (25% scenario).

Reduce electricity use for the most energy-intensive treatment technologies at National Priorities List sites

by 100%	0.4 MMTCO$_2$E per year
by 50%	0.2 MMTCO$_2$E per year
by 25%	0.1 MMTCO$_2$E per year

The most frequently used energy-intensive treatment technologies used at Superfund National Priorities List (NPL) sites are pump-and-treat, thermal desorption, multi-phase extraction, air sparging, and soil vapor extraction. Using data from cost and performance reports compiled by the Federal Remediation Technologies Roundtable and other resources, OSWER estimates that a total of more than 14 billion kilowatt-hours (kWh) of electricity will be consumed through use of these five technologies at NPL sites from 2008 through 2030.[226]

The U.S. Department of Energy estimates that 1.37 pounds of CO$_2$ are emitted into the air for each kWh of electricity generated in the United States. Accordingly, use of these five technologies at NPL sites is anticipated to indirectly result in CO$_2$ emissions totaling 0.40 MMTCO$_2$E annually.[227] If these treatment technologies were optimized, replaced with alternative treatment technologies, or relied on renewable energy sources for power to reduce emissions by 50% or 25%, it would result in a reduction of GHG emissions of 0.20 MMTCO$_2$E or 0.10 MMTCO$_2$E, respectively.

Table 59: GHG Benefits from Optimizing the Top Five NPL Energy-intensive Treatment Technologies

Technology	Estimated CO2 Emissions Annual Average	
Pump & Treat	323,456	MTCO$_2$E
Thermal Desorption	57,756	MTCO$_2$E
Multi-Phase Extraction	12,000	MTCO$_2$E
Air Sparging	6,499	MTCO$_2$E
Soil Vapor Extraction	4,700	MTCO$_2$E
Technology Total	*404,411*	MTCO$_2$E
	= 0.40	MMTCO$_2$E
	X 50%	
	= 0.20	MMTCO$_2$E
	X 25%	
	= 0.10	MMTCO2E

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[225] U.S. Department of Energy, Energy Information Administration. 2009. Annual Energy Outlook. Table 16. Available at: http://www.eia.doe.gov/oiaf/forecasting.html

[226] U.S. EPA. Office of Solid Waste and Emergency Response. 2008. *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites*. EPA 542-R-08-002. p. 20. Available at: htts://www.clu-in.org/download/remed/green-remediation-primer.pdf

[227] Ibid.

Reforest percentage of qualifying former mine lands for carbon sequestration

100%	4 $MMTCO_2E$ per year
50%	2 $MMTCO_2E$ per year
25%	1 $MMTCO_2E$ per year

There are an estimated 2.8 million acres of former mine lands tracked by EPA and states where data were available. Of this, we estimate approximately 890,000 acres are suitable for revegetation, which would yield an annual carbon sequestration benefit of 4 $MMTCO_2E$. The total acreage estimate is detailed in Table 60 and was calculated as described below.

Table 60: Estimated Total Acreage of Former Mine Land

Data Source	Estimated Acreage
AML/ CERCLIS (hardrock)	1,573,763
State Estimates from Mine Waste Technology Program (hardrock)	336,257
OSM (coal mines)	923,053
TOTAL*	2,833,073

*Note: There may be some duplication in sites among data sources.

AML/CERCLIS Estimate

The Abandoned Mine Land / Comprehensive Environmental Response, Compensation, and Liability Information System (AML/CERCLIS) estimate was partially derived from the AML Reference Notebook Appendix A (September 2004), the EPA AML Team Site List (October 2007), and a CERCLIS data pull from December 10, 2007. We coordinated the development of the list of EPA Hardrock AMLs and discussed characteristics of mine sites available in CERCLIS and the acreage data for mine sites in CERCLIS with the EPA AML Team. In addition, CERCLIS experts determined which acreage values in CERCLIS are most appropriate and provided advice on use of the different values.

The original AML inventory of 562 sites (and detailed site area data) was compiled from 2002-2004, from the CERCLIS database and limited information gathered from EPA Regional staff. Because the data are entered by the individual EPA Regions, data quality may be inconsistent among Regions. Data queried from the CERCLIS database was manipulated and entered into a spreadsheet with multiple information categories for each AML site. Further research from Internet and other mine-related resources was then used to fill in any identified data gap, resulting in the AML Team AML Inventory. This inventory is an initial step toward a more collaborative and complete inventory to be developed by the AML Team.

The AML/CERCLIS estimate includes only AMLs with EPA involvement. Site acreage corresponds to: 1) site size from 2004 AML inventory (converted to acres when possible); 2) acres ready for reuse (RAU_ACRES) from December 10, 2007, CERCLIS data pull; or 3) site acreage (SITE_ACRES) from December 10, 2007, CERCLIS data pull.

EPA's AML list contains mills, phosphate waste, smelters, and other processing facilities that might not be considered traditional AMLs by other programs. There is site-specific data available for 36% of the sites in the current EPA AML inventory. It should be noted that three very large sites make up 61% of the total acreage:

- COD980717557 (400 square miles) is a watershed that extends from the Continental Divide east to Denver; an unknown fraction of the 400 square miles is contaminated.
- UTD980667208 (320 square miles) contains radioactive waste.
- MOD981507585 (160,000 acres) is a site with much of its contamination related to groundwater from underground mines and leaching from large tailings piles and ground contamination.

State Estimates from EPA/DOE Mine Waste Technology Program (MWTP)

We relied on the EPA/DOE MWTP annual report to develop the estimate of state-tracked mine land.[228] This report includes data collected from the Bureau of Land Management, Department of the Interior, the Bureau of Mines, the U.S. Forest Service, Earthworks, the U.S. Geological Survey, the National Park Service, the U.S. Government Accountability Office, U.S. Department of Agriculture, and the Western Governors Association which includes AK, AZ, CA, CO, ID, MT, NM, OR, SD, TX, UT, and WY in its membership.

OSM Data (coal mines)

We relied on a U.S. Department of Agriculture publication for the estimated baseline acreage of coal mines requiring reclamation: "There were approximately 1.1 million acres of abandoned coal-mined land needing reclamation in 1977."[229] Additional Abandoned Mine Land Inventory System (AMLIS) data provided by OSM indicates that 176,946 acres of the 1.1 million total acres were reclaimed since 1977, leaving unreclaimed acreage of 923,053. This estimate includes Eastern states only and may contain some underground mines.

The next step in the analysis involved estimating the portion of the total former mine land acreage that was unforested, and therefore could be reforested for carbon sequestration GHG emission benefits. The portion of former mine sites that could be reforested was estimated as shown in Tables 61 and 62 based on the following considerations:

- Knowledge of specific sites and consideration of the location of those sites within each state.
- Utilization of U.S. Geological Survey forest maps to assess the forested area in each state and in the area of major mine sites, and the change in forested area over time.
- Consideration of the weighed impact of the largest sites.
- AMLIS and historical documents to come up with the rough estimate for reforestation potential.

Table 61: Estimated Former Mine Land Acreage with Reforestation Potential – Summary

Abandoned Mine Land Data Source	Acreage	Estimated Reforestation Potential of AMLs	Estimated Acreage with Reforestation Potential
AML/ CERCLIS (hardrock)	1,573,765	Variable 5% - 75% *(See detail below)*	659,424
State Estimates from MWTP (hardrock)	336,457		
OSM (coal mines)	923,053	25%	230,763
TOTAL	2,833,275		890,188

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[228] U.S. EPA and U.S. DOE. 2004. *Mine Waste Technology Program 2004 Annual Report*. Available at: http://www.epa.gov/ORD/NRMRL/std/mtb/mwt/annual/annual2004/mwtp2004annualrpt.pdf

[229] United States Department of Agriculture, Natural Resources Conservation Service. *Rural Abandoned Mine Program*. Post-2001. Available at: http://www.nrcs.usda.gov/programs/ramp/

Table 62: Estimated Former Hardrock Mine Land Acreage with Reforestation Potential – Detail

State	*AML/ CERCLIS Acreage Total*	*State Estimates from MWTP*	Total Hardrock Lands	Estimated Reforestation Potential of AMLs	Estimated Hardrock Acreage with Reforestation Potential
AK	*0*	*28,680*	28,680	35%	10,038
AL	*0*	*0*	0	50%	0
AR	*0*	*0*	0	50%	0
AZ	*24,772*	*136,652*	161,424	5%	8,071
CA	*22,407*	*Accurate acreage information unavailable*	22,407	20%	4,481
CO	*293,943*	*26,584*	320,527	20%	64,105
FL	*11,531*	*0*	11,531	50%	5,766
ID	*16,640*	*18,465*	35,105	50%	17,553
IL	*3,376*	*0*	3,376	50%	1,688
IN	*229*	*0*	229	50%	115
KS	*22,694*	*0*	22,694	25%	5,674
KY	*450*	*0*	450	40%	180
ME	*27*	*0*	27	75%	20
MI	*2,660*	*Accurate acreage information unavailable*	2,660	45%	1,197
MO	*812,763*	*0*	812,763	50%	406,382
MT	*81,845*	*11,256*	93,101	30%	27,930
NC	*2*	*0*	2	60%	1
NE	*6,430*	*0*	6,430	25%	1,608
NJ	*251*	*0*	251	40%	100
NM	*1,877*	*13,585*	15,462	15%	2,319
NV	*13,654*	*Accurate acreage information unavailable*	13,654	5%	683
NY	*5*	*0*	5	65%	3
OH	*200*	*0*	200	55%	110
OK	*25,655*	*0*	25,655	45%	11,545
OR	*648*	*61,180*	61,828	40%	24,731
PA	*800*	*0*	800	65%	520
SC	*152*	*0*	152	60%	91
SD	*4,300*	*4,775*	9,075	15%	1,361
TN	*11*	*0*	11	60%	7
TX	*9,331*	*17,300*	26,631	10%	2,663
UT	*208,450*	*12,780*	221,230	25%	55,308
VA	*84*	*0*	84	60%	50
VT	*30*	*0*	30	70%	21
WI	*0*	*200*	200	40%	80
WA	*8,548*	*0*	8,548	50%	4,274
WY	*0*	*5,000*	5,000	15%	750
TOTAL	*1,573,765*	*336,457*	1,910,222		*659,424*

Based on this analysis, 890,188 acres of former hardrock and coal mine land were estimated as viable for reforestation.

The rate of sequestration from reforestation varies based on soil characteristics, vegetation, climate, land management practices, and other factors. As such, the estimated average rate of sequestration from reforestation varies based on the data source used. A number of studies and sources were considered for use in this report, including IPCC data. This study determined that the best available estimate was from a meta-analysis presented in the Journal of Environmental Quality in 2006.[230]

The Journal of Environmental Quality study derived an average annual rate of carbon sequestration using multiple independent studies and estimates, including IPCC data, to estimate the aggregate average carbon sequestration potential via revegetation on mine lands. The annual rates of carbon accumulation from all studies were combined to generate an average value range equivalent to 3.6-4.2 $MTCO_2E$ per year. To ensure consistency across the data underlying the aggregated average range of carbon sequestration potential, the authors restricted the time frame for applying the average rate of sequestration to 20 years. However, all of the underlying data sources indicated that carbon sequestration in the litter layer and aboveground biomass continued for much longer. As such the total technical potential estimate for revegetating abandoned mine land (i.e., 3.2-3.7 $MMTCO_2E$ per year), should only be applied as an estimate for years 0-20; however, available research indicates that additional carbon sequestration potential exists beyond year 20.

This estimate represents the potential carbon sequestration benefits of revegetation. However, soil amendments are required to address contamination and enable re-vegetation at many abandoned mine lands. Early research has shown that if biosolids or other soil amendments were used to enrich the soil with carbon, greater sequestration could occur. EPA is currently assessing the carbon sequestration potential of organic soil amendments and revegetation, but this analysis is not yet available.

As shown in Table 63, reforesting approximately 890,000 acres of former mine land would result in a GHG emission benefit of 3.2-3.7 $MMTCO_2E$ per year.

Table 63: Estimated GHG Emission Benefit of Reforesting ~890,000 Acres of Former Mine Land

Estimate Range	$MTCO_2E$ per Year	Acreage	$MTCO_2E$ per Year	$MMTCO_2E$ per Year
Low	3.6	890,188	3,204,677	3.2
High	4.2	890,188	3,738,790	3.7

As shown in Table 64, reforesting approximately half of this acreage, or ~445,000 acres of former mine land would result in a GHG emission benefit of 1.6-1.9 $MMTCO_2E$ per year.

Table 64: Estimated GHG Emission Benefit of Reforesting ~445,000 Acres of Former Mine Land

Estimate Range	$MTCO_2E$ per Year	Acreage	$MTCO_2E$ per Year	$MMTCO_2E$ per Year
Low	3.6	445,094	1,602,338	1.6
High	4.2	445,094	1,869,395	1.9

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[230] Sperow, M. "Carbon Sequestration Potential in Reclaimed Mine Sites in Seven East-Central States." *Journal of Environmental Quality*. Jul/Aug, 2006. 35:1428-1438. Available at: http://jeq.scijournals.org/cgi/reprint/35/4/1428

As shown in Table 65, reforesting approximately half of this acreage, or ~223,000 acres of former mine land would result in a GHG emission benefit of 0.8-0.9 $MMTCO_2E$ per year.

Table 65: Estimated GHG Emission Benefit of Reforesting ~223,000 Acres of Former Mine Land

Estimate Range	$MTCO_2E$ per Year	Acreage	$MTCO_2E$ per Year	$MMTCO_2E$ per Year
Low	3.6	222,547	801,169	0.8
High	4.2	222,547	934,697	0.9

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