

Agriculture Emissions in the United States

The agricultural sector affects the climate system in four distinct, but interrelated, ways outlined below and explored further in the subsequent sections of this overview.

- **Greenhouse gas emissions associated with agriculture**

Agriculture is directly responsible for 7 percent of total U.S. greenhouse gas (GHG) emissions, largely from soil management (fertilizer use) and livestock; the agricultural sector is also an end user for electricity and transportation fuels.

- **Agriculture and carbon storage**

Agriculture affects the global carbon cycle because agricultural practices and land use alter the amount of carbon stored in plant matter and soil, and consequently, the amount of carbon dioxide (CO₂) in the atmosphere.

- **Energy and product substitution from agriculture**

Biomass from the agricultural sector can be used to displace fossil fuels for energy purposes and to make a variety of bio-based products.

- **Agriculture and the climate system: beyond GHGs**

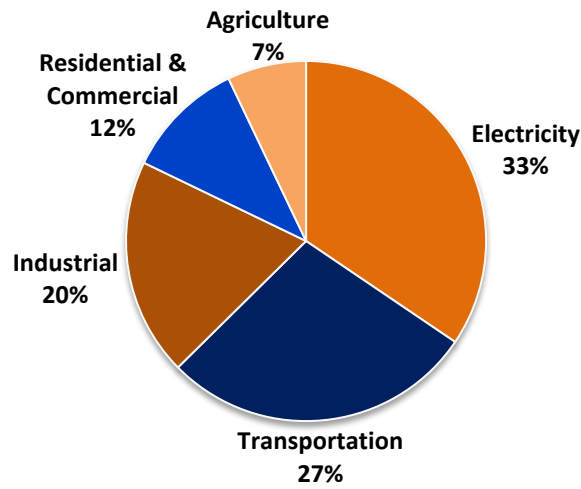
Agriculture also interacts with the climate system in an important way that is not related to GHG emissions or storage by changing the amount of heat absorbed or reflected by the earth's surface.

Although this overview does not aim to address the wide range of observed and projected impacts of climate change on agriculture, it is important to note that agriculture will be affected in a variety of ways as temperatures rise and precipitation patterns change (see [Climate Change 101: Science and Impacts](#)). The impacts of climate change on agriculture will vary by crop, across regions, and through time.¹ Since the linkages between climate and agriculture are dynamic, the impacts of the climate on agriculture will in turn alter the way agriculture affects the climate.

Greenhouse Gas Emissions Associated with Agriculture in the United States

Direct GHG emissions from the U.S. agricultural sector account for 7 percent of total U.S. emissions (see Figure 1).

Figure 1: U.S. Greenhouse Gas Emissions by Sector (2009)



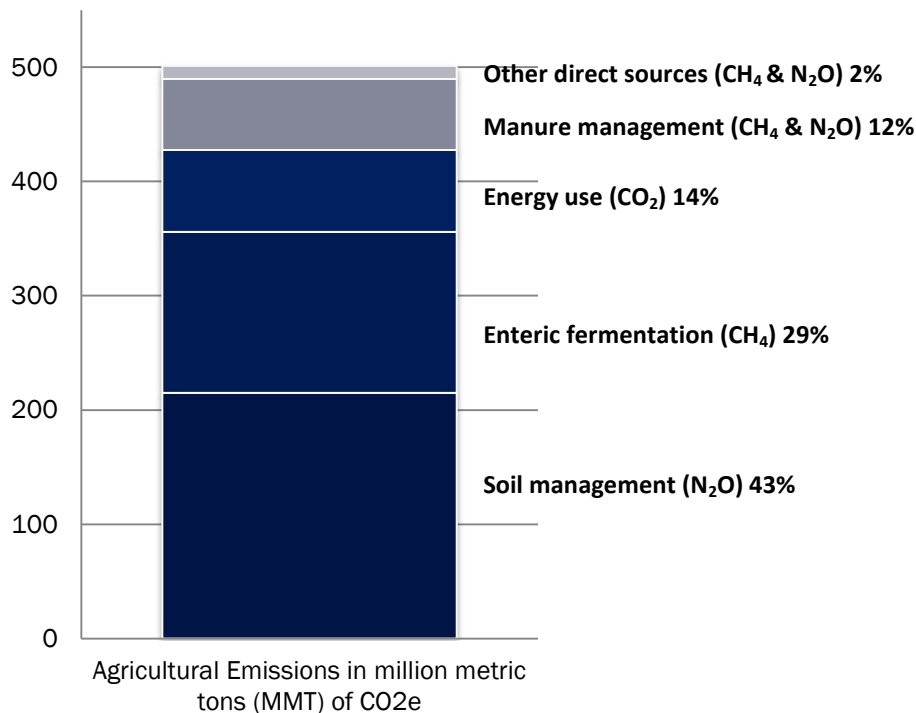
Source: U.S. Environmental Protection Agency (EPA), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*, Table ES-7, 2011. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

Direct GHG emissions from agriculture include methane (CH₄) and nitrous oxide (N₂O) emissions from a relatively small number of sources (see Figure 2). Distributing emissions from electricity and transportation among end-use sectors modestly increases the amount of GHG emissions attributable to the agricultural sector to roughly 8 percent of total U.S. emissions.²

Agricultural soil management, including the application of nitrogen-based fertilizers, accounts for nearly half of all agricultural emissions. Enteric fermentation, a normal digestive process in animals that produces methane, is the second largest source (nearly 30 percent) of agricultural emissions; beef and dairy cattle account for nearly 95 percent of emissions from enteric fermentation. Livestock manure management accounts for an additional 12 percent of emissions. Other emissions sources, including rice cultivation and the field burning of agricultural residues, account for the remaining 2 percent of non-energy related direct GHG emissions from agriculture.³

Energy use is the third largest source of emissions, accounting for 14 percent of total agricultural emissions (see Figure 2). Both direct energy use in support of farming activities, such as the electricity used to power irrigation pumps and the liquid fuels for vehicles used in the fields, and indirect energy use, which includes the emissions from the production of commercial fertilizers and other energy-intensive farm inputs, produce emissions.

Figure 2: Emissions from Agriculture by Source in Million Metric Tons (2008)⁴



Source: U.S. Department of Agriculture (USDA), *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008*, Table 1-2, 2011. http://www.usda.gov/oce/climate_change/AFGGInventory1990_2008.htm

Agriculture and Carbon Storage

Plants, including agricultural crops, play an integral role in the global carbon cycle. The carbon cycle consists of four major stocks of carbon: the atmosphere, the oceans, the terrestrial biosphere (vegetation and soils), and sediments and rocks. Carbon moves from one stock to another at different rates through a variety of pathways. Plants, for example, convert atmospheric CO₂ into a usable form of chemical energy, sugar, through photosynthesis. As the plants use the sugar's energy, some of the carbon is released back into the atmosphere as CO₂, and the rest of the carbon is used by the plant to grow new biomass. The carbon embodied by terrestrial plants can then replenish the carbon in soil, for example, through the decomposition of fallen leaves.⁵

The agricultural sector affects carbon storage in two main ways:

- **Land use conversion**

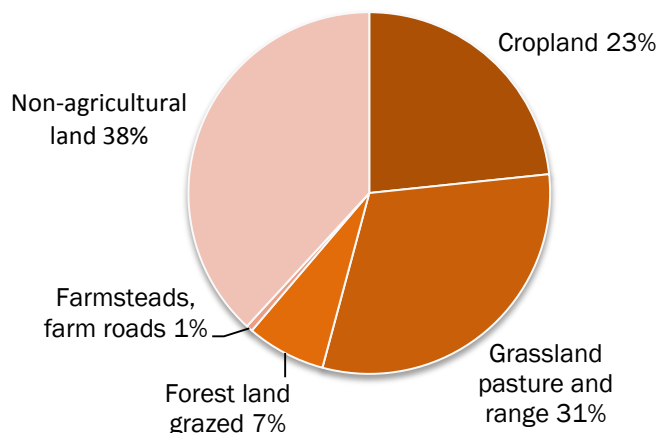
Converting land from one land use to another can result in significant changes to the amount of stored carbon; forests and wetlands generally store more carbon than grasslands, which in turn tend to store more carbon than croplands.

- **Land management practices**

A variety of land management practices can help maintain and increase the amount of stored carbon on agricultural lands. These practices include agroforestry, improved cropping systems, improved nutrient and water management, conservation tillage, water management, and maintenance of perennial crops.⁶

The U.S. Department of Agriculture classifies 62 percent of land in the contiguous 48 states as agricultural and 52 percent of land in all 50 states (see Figure 3).

Figure 3: Land Use in the Contiguous 48 States

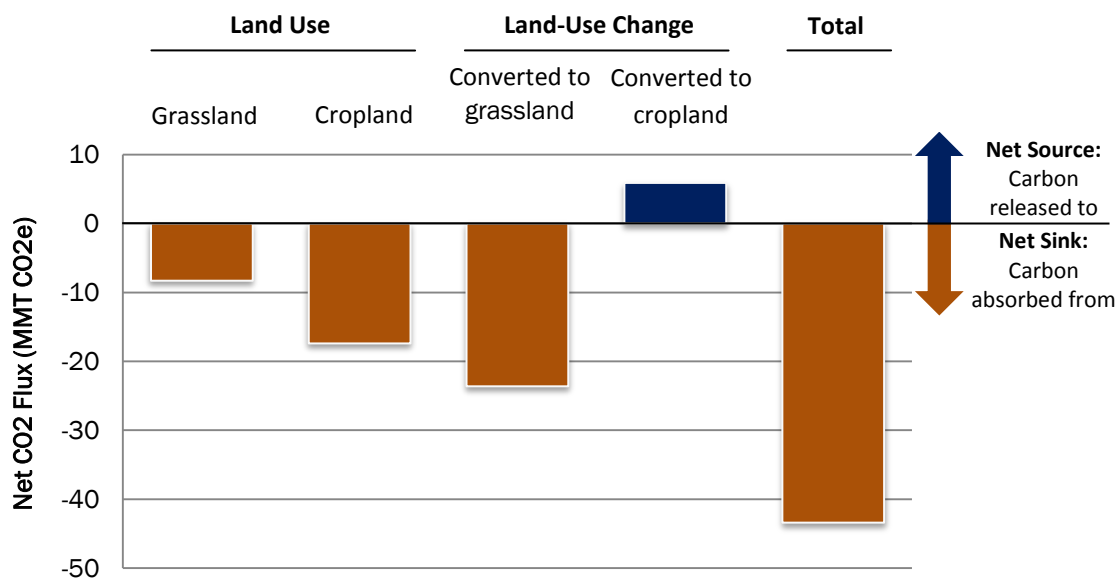


Source: USDA Economic Research Service. *Uses of Land in the United States, 2002*, Table 1, 2005.
<http://www.ers.usda.gov/Publications/EIB14/>

The U.S. Environmental Protection Agency (EPA) has estimated the annual carbon fluxes associated with land use, land-use change, and forestry for the contiguous 48 states. Land-use practices and land-use change can result in either a net release of carbon stored in the plants and soil (making the system a carbon source) or a net uptake of carbon by the plants and soil (making the system a carbon sink).

For agricultural lands, specifically croplands and grasslands, the annual carbon flux values include changes to the amount of carbon stored in soils due to land management and changes in land use, as well as the CO₂ emissions resulting from the application of lime and urea fertilizer. Collectively, agricultural lands in the United States act as a small carbon sink, storing more carbon than they release (see Figure 4). For comparison, forests act as a much larger carbon sink in the United States, storing about 20 times more carbon than the total carbon sink provided by all agricultural lands.⁷

Figure 4: Changes in Carbon Storage of Agricultural Land in 2009



Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*, Table 7-1, 2011. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

Based on the emissions measured by the EPA, agricultural land use and land-use change act as a small net sink for GHG emissions. However, when GHG emissions (Figure 2) and carbon storage (Figure 4) are totaled, the sector is a net source of GHG emissions on a CO₂-equivalent basis.⁸

Energy and Product Substitution from Agriculture

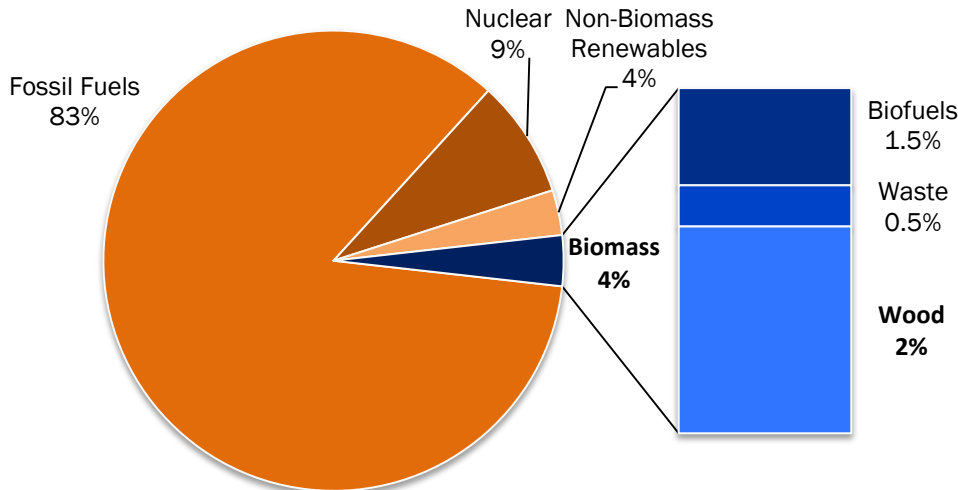
The agricultural sector is one source of biomass for bio-based products and energy. Bio-based products include a broad range of commercial and industrial items, excluding food and feed, that range from plastics to bedding made completely or in large part from agricultural and forestry products.⁹ Agricultural biomass, which can include waste materials or dedicated energy crops, can also be used to produce electricity, heat, and liquid fuels, broadly referred to as *bioenergy*.¹⁰

Substituting biomass for fossil fuels in energy production has the potential to reduce GHG emissions. The combustion of fossil fuels adds to the atmosphere CO₂ that has been stored in deep rock formations for millions of years. The combustion of biomass returns the atmospheric CO₂ taken up through photosynthesis and converted into new plant material, making bio-based fuels theoretically carbon neutral. However, the full climate impact of bioenergy requires a broader assessment that accounts for the life-cycle emissions associated with the biomass, including land management practices, land use change, conversion processes and associated energy use, and transportation.¹¹

In 2009, biomass (including biomass from wood and non-agricultural waste) provided 4 percent of total energy consumed in the United States, or just over half of all renewable energy (see Figure 5: U.S. Energy Consumption by Energy Source with Biomass Breakdown, 2009, Figure 5). For more information on biofuels,

see [CLIMATE TECHBOOK: Biofuels Overview](#).

Figure 5: U.S. Energy Consumption by Energy Source with Biomass Breakdown, 2009



Source: Energy Information Administration (EIA), *U.S. Energy Consumption by Energy Source, 2003-2009*, Table 1, 2008.
http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table1.html

Agriculture and the Climate System: Beyond Greenhouse Gases

The interface between terrestrial ecosystems and the climate system encompasses a wide range of complex interactions that includes, but is not limited to, GHG emissions and carbon storage. Agriculture also affects the amount of solar energy that the land surface absorbs or reflects. The fraction of solar energy reflected by a surface is known as the albedo; bright surfaces like ice and snow that reflect a lot of solar energy have a high albedo, while dark surfaces, like the ocean, have a low albedo and tend to absorb greater amounts of solar energy.

Albedo is important to the climate system because absorbed sunlight warms the surface and is released back into the atmosphere as heat.¹² Darker vegetation and exposed soils tend to absorb more sunlight and, therefore, release more heat into the atmosphere, producing a local warming effect. This warming can play an important role in the overall climate system.¹³

Global Context

Agricultural land, which includes cropland, managed grassland, and permanent crops, occupies about 40-50 percent of the world's total land surface. In 2005, non-energy direct GHG emissions from agriculture accounted for 10-12 percent of total global GHG emissions from human-made sources. Agriculture accounts for 60 percent of global N₂O emissions and 50 percent of CH₄ emissions. A combination of population growth and changing diets has led to increased emissions of these gases from the agricultural sector since at least 1990.¹⁴ This increase can be attributed to the increased use of nitrogen-based fertilizers and the increased number of livestock being raised, especially cattle.¹⁵

Population growth, changing diets, and changing standards of living will continue to affect the amount and

type of food demanded. Recent years have also seen greater interest in and demand for dedicated energy crops. These trends have several possible implications on GHG emissions:

- Increasing land use change to increase the amount of cropland available for food or energy crops will affect carbon storage. The effect of land use change on carbon change will depend on a variety of factors, including previous land use, land management practices, and type of crops grown. An expansion of croplands could result in an overall loss of plant and soil carbon.
- Increasing crop yields will likely require more inputs, such as water and fertilizer, for a given a unit of land. Increasing agricultural inputs will result in higher emissions per unit of agricultural output because more energy will be required to produce the inputs and direct emissions from fertilizer use will increase.
- Rising demand for meat and dairy products will increase methane emissions from enteric fermentation and manure production. The Intergovernmental Panel on Climate Change (IPCC) projects that methane emissions from livestock could increase 60 percent by 2030, depending on whether GHG-mitigating feeding practices and manure management are used.¹⁶ Larger livestock populations could also result in land use change to create grazing lands.

Growing interest in the lifecycle carbon emissions of food may also change patterns of food production and consumption. Lifecycle emissions arise from agricultural inputs (including water and fertilizer), equipment for cultivating and harvesting crops, and transportation to consumers. Possible outcomes of using lifecycle analysis include more localized production—producing food close to its point of consumption—and using organic farming methods that minimize fertilizer use. Particularly in today's globalized food market, accounting for life cycle emissions will be crucial in reducing GHG emissions associated with agriculture and livestock.

Agriculture Sector Mitigation Opportunities

The agricultural sector can contribute to climate change mitigation in a variety of ways. Mitigation efforts can reduce the direct GHG emissions from agriculture, increase carbon storage, substitute bio-based products and feedstocks for fossil fuels, and reduce the amount of heat absorbed by the earth's surface. Some of these mitigation opportunities provide relatively straightforward solutions, but others face a variety of challenges, including the accurate measurement of GHG fluxes.

Mitigation Opportunities

Mitigation opportunities can be identified from each of the four types of interactions that agriculture has with the climate system. A wide range of options exist, but with different levels of technical feasibility, cost-effectiveness, and measurement certainty. A number of the mitigation options for the agricultural sector, including soil management practices, also bring a variety of co-benefits, such as improved water quality and reduced erosion. To date, a number of policies thought to have climate benefits have been pursued in order to achieve one or more of these co-benefits.

- **Reduce GHG emissions**

- *Reduce GHG emissions from energy use*

Energy-related GHG emissions from the agricultural sector can be reduced in a number of ways, including the use of more fuel-efficient machinery and the installation of on-site renewable energy systems for electricity.
- *More efficient fertilizer use*

Increasing the efficiency of nitrogen use reduces the need for additional fertilizer inputs. This can be achieved by fertilizing during the most appropriate period for plant uptake, fertilizing below the soil surface, and balancing nitrogen fertilizers with other nutrients that can stimulate more efficient uptake. These measures can reduce N₂O emissions.
- *Improved manure management*

When manure is held in an oxygen-poor (anaerobic) environment—such as a holding tank—for an extended period of time, bacteria decompose this material and release methane as a byproduct. Reducing the moisture content and the amount of storage time are two options for reducing methane emissions from manure.
- *Improved animal feed management*

Facilitating the digestive process for livestock—such as using easy-to-digest feed—can reduce methane emissions from enteric fermentation.
- *Improved rice cultivation practices*

When rice paddies are flooded, the oxygen-poor (anaerobic) environment allows certain bacteria to create methane through a process called methanogenesis. Periodically draining rice paddies can inhibit this process by aerating the soil.
- **Increase vegetation and soil carbon stocks**
 - *Land-use changes to increase soil carbon*

Reforestation and afforestation initiatives can increase the amount of biomass in a given area of land, thereby sequestering carbon in plant material.
 - *Land management practices that increase soil carbon*

A variety of land management practices can be implemented to increase soil carbon. These include the use of high-residue crops, such as sorghum, that produce a large amount of plant matter left in the field after harvest; the reduction or elimination of fallow periods between crops; the efficient use of manures, nitrogen fertilizers, and irrigation; and the use of low- or no-till practices. Importantly, local conditions will determine the best practices for a given location, and all of these practices do not increase carbon storage in all locations.
- **Substitute biomass feedstocks and products for fossil fuels**

The use of bio-based products as fuels and product substitutes has the potential to reduce fossil fuel combustion and associated GHG emissions. However, careful life-cycle analysis is necessary to

ensure that the substitution yields a net reduction of GHG emissions.

- **Non-GHG related climate interactions**

Less attention has been given to mitigation options that do not affect GHG emissions, but a 2009 study did suggest that crops could be bred or genetically engineered to be more reflective to help reduce warming by reflecting more solar energy from the land surface.¹⁷

Uncertainty and Mitigation Potential

Key aspects of the agricultural sector's climate interactions involve complex biological processes. These processes continue to be studied by scientists to fill gaps in our understanding of how these processes work and to reduce the uncertainty associated with current data on GHG fluxes from agricultural systems. Although the agricultural sector is sometimes identified as having a potentially large role in mitigating climate change, especially by increasing carbon storage in developing countries,¹⁸ further scientific advances will be necessary for the agricultural sector to achieve its full mitigation potential.

Estimates of agriculture's mitigation potential in the United States vary for different practices. For example, emissions of N₂O could be reduced by 30 to 40 percent with improved fertilization practices. Methane (CH₄) emissions could be reduced by 20 to 40 percent by improving livestock and methane management. Croplands could store up to 83 MMT of carbon per year, equivalent to about 1 percent of total U.S. GHG emissions, through widespread adoption of best management practices.¹⁹

¹ For more information, see Intergovernmental Panel on Climate Change (IPCC). "Food, fibre and forest products." In *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report. Cambridge: Cambridge University Press, 2007. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter5.pdf>

² To calculate this value, two datasets are used. Emissions from energy use come from: U.S. Department of Agriculture (USDA), *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008*, 2011. http://www.usda.gov/oce/climate_change/AFGGInventory1990_2008.htm. Emissions from non-energy use come from: Environmental Protection Agency (EPA), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*, 2011. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

³ EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, 2009. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

⁴ One million metric ton is equal to one teragram. For reference, one million metric ton of CO₂e is equal to 280,000 new cars each being driven 12,500 miles or 90 minutes of U.S. energy consumption or 1 day of U.S. energy emissions from lighting buildings, see U.S. Department of Energy (DOE). *2008 Buildings Energy Data Book*. Prepared for U.S. Department of Energy Office of Energy Efficiency and Renewable Energy by D&R International, Ltd. Silver Spring, MD, 2008. <http://buildingsdatabook.eren.doe.gov/>

⁵ Chapin, F. S., P.A. Matson, H. A. Mooney. *Principles of Terrestrial Ecosystem Ecology*. New York: Springer Science + Business Media, Inc. 2002.

⁶ Richards, K. R., R. N. Sampson, and S. Brown. *Agricultural & Forestlands: U.S. Carbon Policy Strategies*. Prepared for the Pew Center on Global Climate Change, 2006. http://www.pewclimate.org/global-warming-in-depth/all_reports/ag_forestlands

⁷ EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*, 2011. <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>

⁸ The emissions of a gas, by weight, multiplied by its "global warming potential." Global warming potential is a system of multipliers devised to enable warming effects of different gases to be compared. The cumulative warming effect, over a specified time period, of an emission of a mass unit of CO₂ is assigned the value of 1. Effects of emissions of a mass unit of non-CO₂ greenhouse gases are

estimated as multiples. For example, over the next 100 years, a gram of methane (CH₄) in the atmosphere is currently estimated as having 23 times the warming effect as a gram of carbon dioxide; methane's 100-year GWP is thus 23. Estimates of GWP vary depending on the time-scale considered (e.g., 20-, 50-, or 100-year GWP) because the effects of some GHGs are more persistent than others.

⁹ Department of Agriculture. Final Rule. "Designation of Biobased Items for Federal Procurement," *Federal Register* 71, no. 51 (16 March 2006): 13686. <http://www.epa.gov/EPAFR-CONTENTS/2006/March/Day-16/contents.htm>

¹⁰ DOE, Energy Efficiency and Renewable Energy. "Biomass FAQs." http://www1.eere.energy.gov/biomass/printable_versions/biomass_basics_faqs.html. Updated 16 January 2009.

¹¹ Paustian, K., J. M. Antle, J. Sheehan, and E. A. Paul. *Agriculture's Role in Greenhouse Gas Mitigation*. Prepared for the Pew Center on Global Climate Change, 2006. http://www.pewclimate.org/global-warming-in-depth/all_reports/agriculture_s_role_mitigation

¹² Chapin et al. 2002.

¹³ Ibid.

¹⁴ Intergovernmental Panel on Climate Change (IPCC). "Agriculture." In *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report. Cambridge University Press: Cambridge, 2007. <http://www.ipcc.ch/ipccreports/ar4-wg3.htm>

¹⁵ IPCC 2007.

¹⁶ IPCC 2007.

¹⁷ Ridgwell, A., J. S. Singarayer, A. M. Hetherington, and P. J. Valdes. "Tackling Regional Climate Change by Leaf Albedo Bio-Geoengineering" *Current Biology* 19 (2). (2009).

¹⁸ IPCC 2007.

¹⁹ Paustian et al. 2006.