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Nitrous Oxide from Agricultural Sources: Potential Role in Greenhouse Gas Emission Reduction and Ozone Recovery

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Summary

Gases other than carbon dioxide accounted for nearly 15% of U.S. greenhouse gas emissions in 2007, yet there has been minimal discussion of these other greenhouse gases in climate and energy legislative initiatives. Reducing emissions from non-carbon dioxide greenhouse gases, such as nitrous oxide (N_2O), could deliver short-term climate change mitigation results as part of a comprehensive policy approach to combat climate change.

Nitrous oxide is 298 times more potent than carbon dioxide in its ability to affect climate change; and moreover, results of a recent scientific study indicate that nitrous oxide is currently the leading ozone-depleting substance. Thus, legislation to restrict nitrous oxide emissions could contribute to both climate change protection and ozone recovery.

The primary human source of nitrous oxide is agricultural soil management, which accounted for two-thirds of the N_2O emissions reported in 2007 (approximately 208 million metric tons CO_2 equivalent). One proposed strategy to lower N_2O emissions is more efficient application of synthetic fertilizers. However, further analysis is needed to determine the economic feasibility of this approach as well as techniques to measure and monitor the adoption rate and impact of N_2O emission reduction practices for agricultural soil management.

As Congress considers legislation that would limit greenhouse gas emissions (both H.R. 2454 and S. 1733 would require that greenhouse gas emissions be reduced by 83% in 2050), among the issues being discussed is how to address emissions of non-CO_2 greenhouse gases. Whether such emissions should be subject to direct regulation, what role EPA should play using its existing Clean Air Act authority, whether the sources of N_2O should be included among the covered entities of a cap-and-trade system, whether N_2O reductions should be considered offsets to be purchased by the covered entities of a cap-and-trade system, and what role USDA should play in any N_2O reduction scheme are among the issues being discussed. How these issues are resolved will have important implications for agriculture, which has taken a keen interest in climate change legislation.

Contents

Figures

Tables

Contacts

Introduction

Policymakers are dedicating considerable attention to climate change mitigation, primarily discussing options for carbon dioxide (CO_2) emission reduction.[1] Less frequently addressed in proposed legislation is emission reduction for non-CO_2 greenhouse gases, such as nitrous oxide (N_2O). However, N_2O reduction efforts have the potential to mitigate climate change. Moreover, N_2O emission sources may be regulated under the existing Clean Air Act as a class I or class II ozone-depleting substance at the discretion of the Environmental Protection Agency (EPA) Administrator. No new legislation needs to be passed to regulate N_2O for climate protection and ozone recovery.

The five non-CO_2 greenhouse gases regularly monitored but not entirely regulated by EPA (methane, nitrous oxide, hydroflourocarbons, perflourocarbons, and sulfur hexaflouride) accounted for nearly 15% of U.S. greenhouse gas (GHG) emissions in 2007, as measured by total tons of CO_2 equivalent.[2] Nitrous oxide—the third most abundant greenhouse gas—was responsible for roughly 4% of total U.S. GHG emissions in 2007 by weight. Although they comprise a smaller portion of GHG emissions, non-CO_2 greenhouse gases, including N_2O, are more potent than CO_2. The gases identified above are 25 to 22,800 times more effective than an equivalent weight of CO_2 at trapping heat in the atmosphere, with N_2O being 298 times more potent by weight.[3]

In addition to being one cause of climate change, N_2O is an ozone-depleting substance (ODS).[4] Indeed, scientific analysis suggests that N_2O is now the leading ODS, as other substances have been reduced significantly owing to regulations enacted in the late 1980s, in the Montreal Protocol on Substances that Deplete the Ozone Layer.[5] N_2O emission reduction could thus play a compelling role in recovery of the ozone layer as well as in climate change remediation.

The agriculture sector is the primary anthropogenic source of nitrous oxide.[6] The bulk of U.S. N_2O emissions stem from fertilizing agricultural soils for crop production. Strategies or

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[1] For more information on CO_2 emission reduction techniques, see CRS Report RL33801, *Carbon Capture and Sequestration (CCS)*, by Peter Folger. For more information on legislative proposals to address climate change and regulation of greenhouse gases under the Clean Air Act, see CRS Report R40556, *Market-Based Greenhouse Gas Control: Selected Proposals in the 111th Congress*, by Jonathan L. Ramseur, Larry Parker, and Brent D. Yacobucci; and CRS Report R40585, *Climate Change: Potential Regulation of Stationary Greenhouse Gas Sources Under the Clean Air Act*, by Larry Parker and James E. McCarthy.

[2] U.S. Environmental Protection Agency, *2009 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-09-004, April 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

[3] The potency of a greenhouse gas is described by its global warming potential (GWP), an estimate of how much a greenhouse gas affects climate change over a quantity of time relative to CO_2, which has a GWP value of 1. Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis* (2007), p. 212.

[4] An ozone-depleting substance is a compound that contributes to stratospheric ozone depletion by releasing chlorine or bromine atoms into the atmosphere when broken down, leading to the destruction of ozone, a substance necessary to prevent harmful UVB rays from reaching Earth.

[5] The Montreal Protocol is an international treaty crafted to protect the stratospheric ozone layer by gradually eliminating a number of ozone-depleting substances.

[6] Also in the agriculture sector, animal digestive systems and manure management account for a large portion of U.S. methane emissions. The Intergovernmental Panel on Climate Change (IPCC) assigns nitrous oxide and methane a global warming potential of 298 and 25, respectively.

technologies designated for N_2O emission reduction are limited.[7] This is partly due to the dispersed nature of N_2O emission sources.

In the agriculture sector, the majority of N_2O is released as a consequence of specific nitrogen cycle processes (nitrification and denitrification) when large amounts of synthetic nitrogen fertilizers are used for crop production. More efficient application of synthetic fertilizers (e.g., precision agriculture, nitrogen inhibitors, nitrogen sensors, controlled-release fertilizer products) is one way to reduce excess amounts of nitrogen available for bacterial processing and eventual release to the atmosphere as N_2O. High costs and difficulty in measuring these products' efficacy, among other deterrents, have hampered widespread adoption of practices to reduce N_2O emissions.

This report focuses on the contributions of N_2O to climate change and ozone depletion. Policy options for N_2O emission reduction, sources of N_2O, and federal support to lower N_2O emissions are discussed.

Nitrous Oxide: A Primer

Nitrous oxide (N_2O), familiar to some as "laughing gas," contributes to climate change and ozone depletion. Once released, N_2O lingers in the atmosphere for decades (its atmospheric lifetime is approximately 114 years) and is 298 times more effective at trapping heat in the atmosphere over a 100-year time frame than carbon dioxide (CO_2).[8] N_2O emission quantity estimates have remained fairly constant over the last few years, hovering around 312 million metric tons carbon dioxide equivalent (CO_2e). See **Table 1**.

Table 1. U.S. Greenhouse Gas Emissions

(million metric tons CO_2e)

Gas / Source	2005	2006	2007	Avg. Contribution[a]
Carbon dioxide (CO_2)	6,090.8	6,014.9	6,103.4	85%
Methane (CH_4)	561.7	582.0	585.3	8%
Nitrous oxide (N_2O)	*315.9*	*312.1*	*311.9*	4%
Hydroflourocarbons (HFCs)	116.1	119.1	125.5	1.7%
Perflouruocarbons (PFCs)	6.2	6.0	7.5	<1%
Sulfur hexaflouride (SF_6)	17.9	17.0	16.5	<1%
Total	7,108.6	7,051.1	7,150.1	

Source: Environmental Protection Agency, *2009 U.S. Greenhouse Gas Inventory Report.*

a. Average contribution to total U.S. greenhouse gas inventory based on data provided for 2005 to 2007.

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[7] Strategies and technologies for N_2O emission reduction are limited in comparison to resources expended for methane capture. Methane capture technologies, as well as financial and technical support, for point sources have been available for decades. For more information on methane capture, see CRS Report R40813, *Methane Capture: Options for Greenhouse Gas Emission Reduction*, by Kelsi Bracmort et al.

[8] S. Solomon, D. Qin, and M. Manning et al., *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth*, IPCC, IPCC WG1 AR4 Report, New York, NY, 2007, http://ipcc-wg1.ucar.edu/wg1/wg1-report.html. The IPCC assigned N_2O a global warming potential of 298 over a 100-year time horizon.

Sources of N_2O Emissions

Nitrous oxide is emitted from anthropogenic (manmade) and natural sources. Oceans and natural vegetation are the major natural sources of N_2O. Agricultural soil management (e.g. fertilization, application of manure to soils, drainage and cultivation of organic soils) is responsible for two-thirds of anthropogenic U.S. N_2O emissions.[9] In 2007, N_2O emissions from agricultural soil management totaled more than 200 million metric tons of CO_2e.[10] Other anthropogenic sources of N_2O are combustion by mobile sources (cars, trucks, etc.), nitric acid production, and manure management.[11]

Figure 1 depicts the origination and passage of nitrogen (N) that leads to N_2O emissions from agricultural soil management. The amount of N_2O emitted from cropland soils largely depends on the amount of nitrogen applied to a crop, weather, and soil conditions. Corn and soybean crops emit the largest amounts of N_2O, respectively, due to vast planting areas, plentiful synthetic nitrogen fertilizer applications, and, in the case of soybeans, high nitrogen fixation rates (**Figure 2**).[12]

The Nitrogen Cycle

Comprehension of the nitrogen cycle (**Figure 3**) is beneficial when crafting policy to reduce N_2O emissions from anthropogenic sources. Nitrogen, an essential element required by organisms to grow, is found throughout the atmosphere in various forms. The nitrogen cycle portrays the routes in which nitrogen moves through the soil and atmosphere in both organic and inorganic form. Certain processes within the nitrogen cycle convert the nitrogen into a form that can be taken up by plants. Four of the major processes are:

- nitrogen fixation—conversion of nitrogen gas (N_2) to a plant-available form;
- nitrogen mineralization—conversion of organic nitrogen to ammonia (NH_3);
- nitrification—conversion of ammonia (NH_3) to nitrate (NO_3-) via oxidation (that is, by being combined with oxygen); and
- denitrification—conversion of nitrates back to nitrogen gas.

Nitrous oxide is a byproduct of nitrification and denitrification. Both processes occur naturally. Excess application of nitrogen fertilizer can lead to increased nitrification, which can cause nitrate to leach into groundwater or surface runoff (in turn, this causes eutrophication, which can damage aquatic environments).

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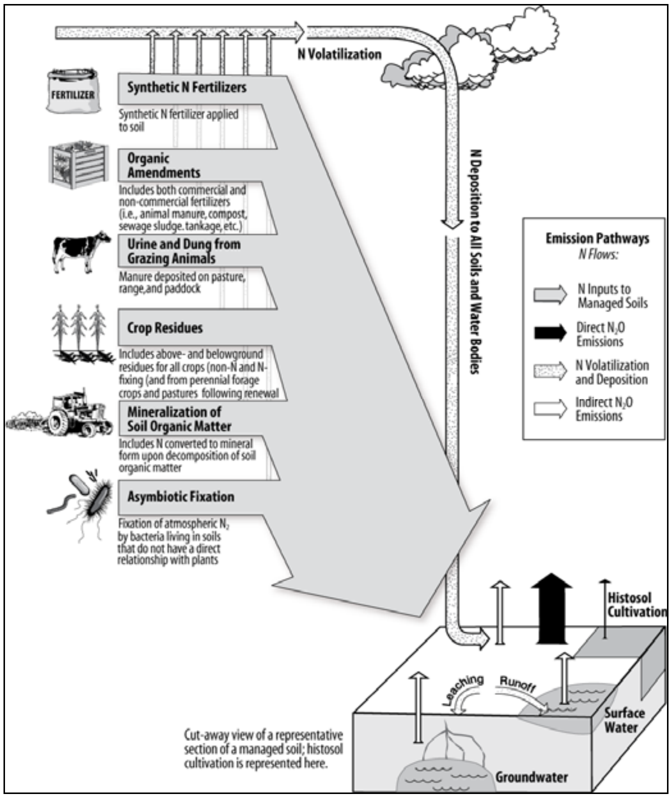
[9] Agricultural soil management includes practices that add to, or create an environment conducive to the release of, mineral nitrogen (N).

[10] U.S. Environmental Protection Agency, *2009 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-09-004, April 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

[11] Mobile (fuel) combustion leads to N_2O being emitted as a byproduct. N_2O is released as a byproduct during the oxidation of ammonia for production of nitric acid, a primary component of synthetic fertilizers and some explosives. N_2O emissions are generally released in large amounts from dry manure handling systems (e.g., pasture, solid storage)..

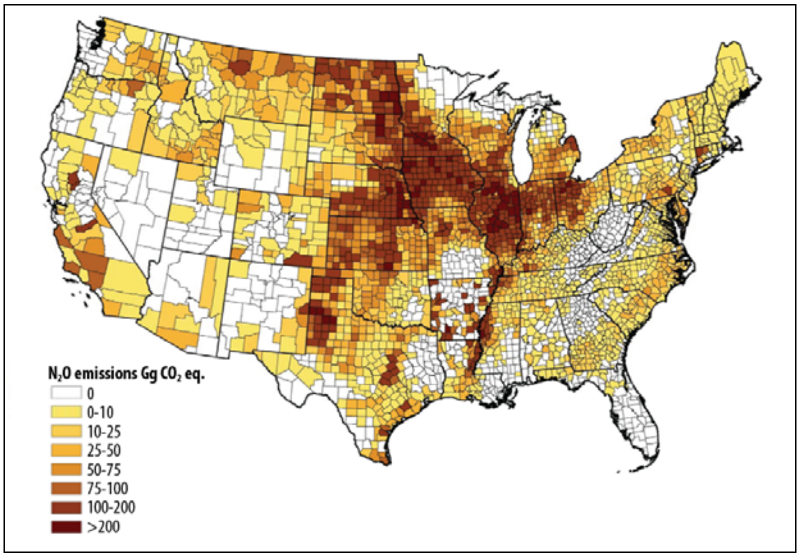
[12] U.S. Department of Agriculture, *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005* , Technical Bulletin No. 1921, 2008, http://www.usda.gov/oce/global_change/AFGGInventory1990_2005.htm. Nitrogen fixation is the conversion of nitrogen gas to ammonia.

Figure 1. Sources and Pathways of Nitrogen (N) Resulting in N_2O Emissions from Agricultural Soil Management



Source: U.S. Environmental Protection Agency, *2009 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-09-004, Chapter 6, April 2009. Adapted by CRS.

Figure 2. County-Level N_2O Emissions from Major Cropped Soils in 2005

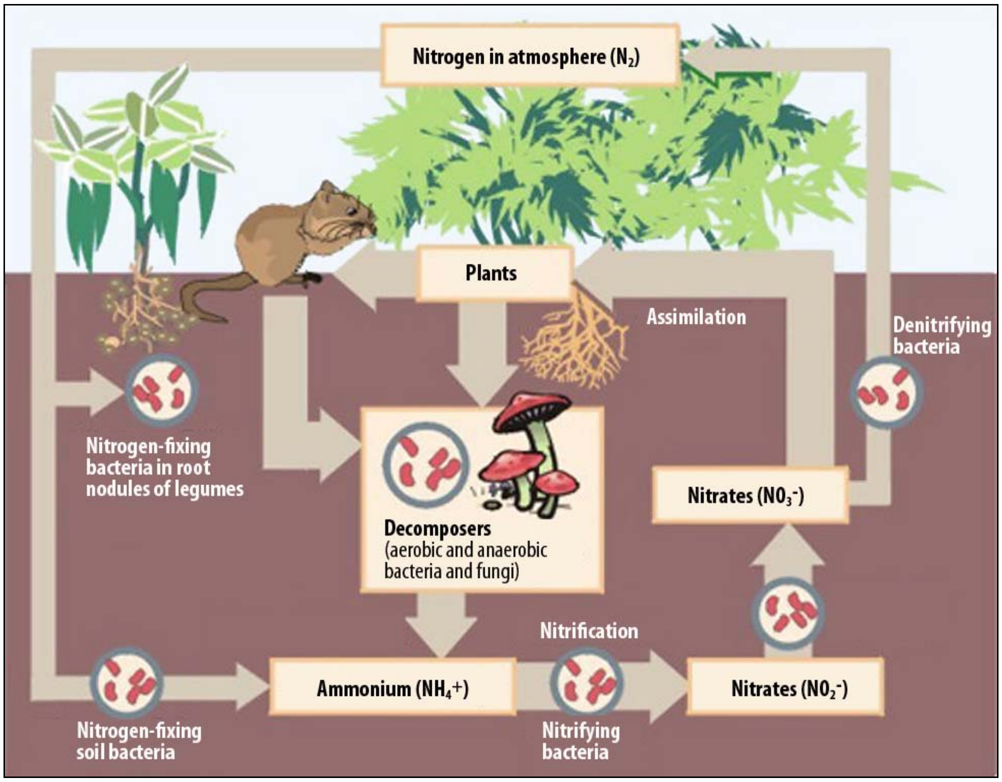


Source: USDA, *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005*. Adapted by CRS.

a. 1 Gigagram (Gg) is equivalent to 1,000 metric tons.

b. Major crops are defined as corn, soybean, wheat, hay, sorghum, and cotton.

Figure 3. The Nitrogen Cycle



Source: EPA. Adapted by CRS

Opportunities and Challenges for Nitrous Oxide Emission Reduction

N_2O emission mitigation options are available for agricultural soil management and nitric acid production. Nitric acid is a chemical compound used to make synthetic fertilizers. N_2O abatement options for nitric acid production include a high-temperature catalytic reduction method, a low-temperature catalytic reduction method, and nonselective catalytic reduction.[13] The estimated reduction efficiencies (the percentage reduction achieved with adoption of a mitigation option) are 90%, 95%, and 85%, respectively.

Agricultural soil management mitigation options recommended by researchers and technology transfer specialists to discourage excess application of nitrogen fertilizers and soil disturbance (**Table 2**) are not generally being practiced. Fertilizer and soil best management practices aim to provide the crop with the nutrient and soil conditions necessary for crop production, and prevent nutrient and soil loss from the crop field (e.g., erosion, leaching).[14] Some may consider less

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[13] U.S. Environmental Protection Agency, *Global Mitigation of Non-CO_2 Greenhouse Gases*, EPA-430-06-005, 2006. Catalytic reduction methods use a catalyst to reduce nitrous oxides in exhaust gas at varying temperatures.

[14] C. S. Snyder, *Fertilizer Nitrogen BMPs to Limit Losses That Contribute to Global Warming* , International Plant Nutrition Institute, Ref. # 08057, June 2008, http://www.ipni.net/ipniweb/portal.nsf/0/6D54ABC2C92D9AFA8525749B0074FF59.

money spent towards fertilizer use an economic incentive for agricultural producers.[15] Others may be concerned to ensure that crop yields meet expected feed, fiber, and fuel mandates (e.g., for corn ethanol), which may be difficult to attain with less fertilizer use.[16] Monitoring reduced nitrogen fertilization applications on a large scale for climate change mitigation purposes may be difficult; it is not clear how such a program could be managed at a national level.[17] Enforcement options could include voluntary verification, third-party verifiers, or government intervention.

Reporting N_2O emissions from agricultural soil management was not included in the Final Mandatory Reporting of Greenhouse Gases Rule issued by EPA on September 22, 2009.[18] EPA's reasoning behind this decision was that no low-cost or simple direct N_2O measurement methods exist. Additionally, EPA released a proposed rule requiring new or modified facilities that could trigger Prevention of Significant Deterioration (PSD) permitting requirements to apply for a revision to their operating permits to incorporate the best available control technologies and energy efficiency measures to minimize GHG emissions.[19]

Table 2. Select N_2O Mitigation Alternatives for Agricultural Soil Management

Mitigation Alternative	Description
Split fertilization	Application of same amount of nitrogen fertilizer as in baseline but divided into three smaller increments during crop uptake period to better match nitrogen application with crop demand and reduce nitrogen availability for leaching, nitrification, denitrification, and volatilization.
Simple fertilization reduction (10%, 20%, or 30%)	Reduction of nitrogen-based fertilizer from one-time baseline application of 10%, 20%, or 30%.
Nitrification inhibitor	Reduces conversion of ammonium to NO_3-, which slows the immediate availability of nitrate (nitrate is water soluble). The inhibition of nitrification reduces nitrogen loss and increases overall plant uptake.
No-till	Conversion from conventional tillage to no-till, where soils are disturbed less and more crop residue is retained.

Source: EPA, *Global Mitigation of Non-CO_2 Greenhouse Gases*, http://www.epa.gov/climatechange/economics/downloads/GM_SectionV_Agriculture.pdf.

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[15] According to the Government Accountability Office, natural gas is the highest-priced factor when producing nitrogen fertilizer. Thus, natural gas prices impact nitrogen fertilizer costs. U.S. General Accounting Office, *Natural Gas: Domestic Nitrogen Fertilizer Production Depends on Natural Gas Availability and Prices*, GAO-03-1148, September 2003, http://www.gao.gov/new.items/d031148.pdf.

[16] For example, the Renewable Fuel Standard (RFS) is a provision established by the Energy Policy Act of 2005 requiring gasoline to contain a minimum amount of fuel produced from renewable biomass (including corn). For more information on the RFS, see CRS Report R40155, *Selected Issues Related to an Expansion of the Renewable Fuel Standard (RFS),* by Brent D. Yacobucci and Randy Schnepf.

[17] For more information on monitoring carbon in agriculture, see CRS Report RS22964, *Measuring and Monitoring Carbon in the Agricultural and Forestry Sectors*, by Ross W. Gorte and Renée Johnson.

[18] For more information on the agricultural implications of the Mandatory Reporting of Greenhouse Gases Rule, see CRS Report RL32948, *Air Quality Issues and Animal Agriculture: A Primer*, by Claudia Copeland.

[19] For more information on the proposed PSD rule, see CRS Report R40585, *Climate Change: Potential Regulation of Stationary Greenhouse Gas Sources Under the Clean Air Act*, by Larry Parker and James E. McCarthy; and EPA, *Proposed Rule: Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule,* 2009, http://www.epa.gov/NSR/fs20090930action.html.

Federal Support for Nitrous Oxide Emission Reduction

USDA provides some financial and technical assistance for nutrient management through its conservation programs.[20] Moreover, USDA's Agricultural Research Service (ARS) is studying the relationship between agricultural management practices and nitrous oxide emissions.[21]

In addition to the agriculture sector, work is being done in the transportation sector to reduce N_2O emissions. Mobile combustion was responsible for nearly 10% of N_2O emissions reported in 2007.[22] One N_2O emission reduction initiative, proposed by EPA and the Department of Transportation, is to cap tailpipe N_2O emissions at 0.010 grams per mile as part of a wider effort to reduce greenhouse gas emissions and improve fuel economy in tandem, via a CO_2 emission standard for light-duty vehicles.[23] EPA has allocated financial resources to quantify N_2O emissions for the greenhouse gas inventory (e.g., DAYCENT model).[24]

Policy Options for Nitrous Oxide Emission Reduction

Congress has begun to investigate the reduction of non-CO_2 greenhouse gas emissions, including N_2O emissions, as one strategy to mitigate climate change. Some contend that N_2O emissions reduction could serve as a short-term response in the larger, long-term scheme of mitigation and adaptation efforts.[25] It may be viewed as a short-term response because N_2O emissions make up a small amount of the GHG inventory compared to CO_2 emissions. Any substantial approach to mitigate climate change is likely at some point to have to address sources that emit CO_2.

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[20] For more information on agricultural conservation programs, see CRS Report R40763, *Agricultural Conservation: A Guide to Programs* , by Megan Stubbs. For more information on technical assistance for nutrient management, see USDA, Natural Resources Conservation Service, *Conservation Practice Standard—Nutrient Management Code 590*, August 2006, ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/590.pdf.

[21] For more information on the efforts underway at ARS, visit the Air Quality of Agricultural Systems Research Unit website at http://www.ars.usda.gov/main/site_main.htm?modecode=36-25-15-15, or the Air Quality National Program website at http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=203.

[22] U.S. Environmental Protection Agency, *2009 U.S. Greenhouse Gas Inventory Report*, EPA 430-R-09-004, April 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

[23] U.S. Environmental Protection Agency, *EPA and NHTSA Propose Historic National Program to Reduce Greenhouse Gases and Improve Fuel Economy for Cars and Trucks* , EPA-420-F-09-047, September 2009, http://www.epa.gov/otaq/climate/regulations/420f09047.htm.

[24] EPA uses the DAYCENT ecosystem model for the U.S. greenhouse gas inventory "to estimate direct N_2O emissions from mineral cropland soils that are managed for production of major crops—specifically corn, soybeans, wheat, alfalfa hay, other hay, sorghum, and cotton."

[25] Shilpa Rao and Keywan Riahi, "The Role of Non-CO_2 Greenhouse Gases in Climate Change Mitigation: Long-Term Scenarios for the 21st Century," *Energy Journal*, vol. 27 (2006), pp. 1-26; Mario Molina, Durwood Zaelke, and K. Madhava Sarma et al., "Reducing Abrupt Climate Change Risk Using the Montreal Protocol and Other Regulatory Actions to Complement Cuts in CO_2 Emissions," *Proceedings of the National Academy of Sciences of the United States of America*, October 12, 2009.

Congress could approach N_2O emissions reduction as part of a comprehensive GHG emission strategy offering economically attractive abatement alternatives to discourage actions leading to climate change. For example, a cap or fee on N_2O emissions could spur innovative methods for agricultural producers to limit excess synthetic fertilizer application. Congress could also examine the tools necessary to identify N_2O emission abatement options, assess their cost, and determine their economic impact for full incorporation into climate change legislation.

Besides mitigating climate change, reducing N_2O emissions could lead to ozone recovery. Congress could explore the co-benefits that may arise from restricting N_2O emissions for climate change purposes. N_2O is not regulated as an ODS under the Clean Air Act, Title VI, Stratospheric Ozone Protection (as guided by the Montreal Protocol). As emissions of other ODSs (e.g., chlorofluorocarbon-11, halon-1211) have declined due to regulation, N_2O has emerged as the dominant ODS.[26] The first-ever published ozone depletion potential (ODP) value assigned to N_2O, 0.017, is less than the ODP value of 1.0 for the reference gas chlorofluorocarbon 11 (CFC-11). While some may not see a cause for alarm based on the ODP value alone, the quantity of N_2O emissions and its potency as a GHG can lead to serious harm (see **Table 1**).

The ODP value for N_2O does not allow for its mandatory inclusion as a class I substance for regulation under the Clean Air Act.[27] However, N_2O could be listed as a class II substance at the direction of the EPA Administrator or regulated under Section 615 of the act.[28] Class I substances have an ODP of 0.2 or more and are more harmful to stratospheric ozone molecules than Class II substances, which have an ODP of less than 0.2.

With or without ODP substance listing, Congress may find it useful to incorporate the ozone depletion impacts of N_2O into its climate change policy proposals both to reduce greenhouse gas emissions and to further ozone recovery achievements. Classifying N_2O emission reduction as an eligible offset type, including N_2O as a covered entity within a cap-and-trade program, or directing EPA to use existing authority under the Clean Air Act to regulate N_2O are other available options to reduce N_2O emissions for ozone or climate protection. Any option chosen to reduce N_2O emissions will more than likely require an improvement of N_2O estimation, measurement, and reporting methods and possible financial incentives.

Congress could apply lessons learned from previous international agreements that are intended to abolish harmful compounds. The outcomes of the Montreal Protocol, put into action in the late 1980s, may prove useful to Congress in understanding the long-term implications of certain climate change policy options, specifically cap-and-trade. A number of gases were phased out under the Protocol, which allowed for each country to establish a regulatory framework to monitor and reduce ODSs. Certain ozone-depleting substances, such as N_2O, were not included in the Protocol partly because their threat was not perceived as urgent at the time. However, one unintended consequence of the success of the Protocol reducing targeted ODSs is that N_2O has emerged as the leading ODS.

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[26] A. R. Ravishankara, John S. Daniel, and Robert W. Portmann, "Nitrous Oxide (N_2O): The Dominant Ozone-Depleting Substance Emitted in the 21st Century," *Science Express*, August 27, 2009.

[27] 42 U.S.C. § 7671a. The EPA Administrator may add to the list of class I substances any substances that the Administrator determines as having an ozone depletion potential of 0.2 or greater.

[28] 42 U.S.C. § 7671n. The EPA Administrator has the authority to promptly promulgate regulations respecting the control of an ODS by submitting notice of the proposal and promulgation of such regulation to the Congress.

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