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CLIMATE CHANGE AND U.S. AGRICULTURE

JUHA SIIKAMÄKI AND JOSEPH MAHER

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Juha Siikamäki and Joseph Maher

SUMMARY

Despite its relatively small role in generating carbon dioxide (CO_2), agriculture is frequently discussed in the context of climate change—for several reasons. First, agriculture is one of the key sectors of the economy that may be strongly affected by climate change. Second, while relatively unimportant for CO_2 emissions, the agriculture sector is a major source of other greenhouse gas (GHG) emissions, notably nitrous oxide (N_2O) and methane (CH_4). Third, agricultural practices provide opportunities for soil-based carbon sequestration, potentially a relatively cheap mitigation option. Fourth, the recent biofuels boom is transforming U.S. agriculture in ways that have implications not only for GHG emissions and energy production, but also for agriculture and the food sector as a whole. This issue brief brings together each of these aspects of the connection between agriculture and climate change.[1]

Effects of Climate Change on Agriculture

- Climate change is not expected to materially alter the overall ability of the United States to feed its population and remain a strong agricultural exporter. Generally, climate change is predicted to have overall positive but relatively modest consequences on agricultural production in the United States over the next 30 to 100 years. Longer term consequences are less well understood.

- At the regional level, however, projected effects on agriculture are considerable. Climate change is expected to reduce agricultural output in the South but increase production in northern regions, especially the Great Lakes.

- Predicting changes in precipitation patterns, extreme weather effects, pest populations, plant diseases, and other production risks is inherently difficult. Current assessments do not fully account for potential effects on agriculture from these climate impacts.

Agriculture as a Source of GHG Emissions

- The agricultural sector is responsible for roughly 8 percent of total U.S. GHG emissions.

- Agriculture is not a major source of CO_2 emissions, but it is the source of almost 30 percent of methane emissions and 80 percent of nitrous oxide emissions. On a CO_2-equivalent basis, these gases account for nearly 15 percent of all GHG emissions in the United States. Most agricultural nitrous oxide emissions stem from soil management; methane emissions come primarily from animal husbandry (specifically, enteric fermentation in the digestive systems of ruminant animals and manure management).

- While unlikely to be included in a mandatory policy, the agricultural sector is a potential source of low-cost emissions

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[1] Broader issues such as overall energy demand, energy security, climate change agreements, and so forth, are outside the scope of this brief.

offsets. Though these offsets provide important GHG mitigation opportunities, incorporating them in a regulatory system presents challenges in terms of measuring, verifying, and assuring the permanence of claimed reductions.

- Cost-effective GHG mitigation opportunities in the agriculture sector include the use of soil management practices to reduce nitrous oxide emissions and increase carbon sequestration.

- Soil-based carbon sequestration, in particular, may represent an important near-term GHG mitigation option, and a means of keeping mitigation costs down until other emissions-reduction technologies develop.

Biofuels

- Corn-based ethanol production has skyrocketed in recent years, and this trend is likely to continue. Nationwide, nearly 130 ethanol biorefineries with total annual production capacity of 6.7 billion gallons are currently[2] in operation, making the United States the world's largest producer of ethanol.

- The almost 80 new plants currently under construction will approximately double current U.S. ethanol production capacity.

- With more than 13 billion gallons of annual production capacity either already in operation or under construction, domestic ethanol use is poised to far exceed the 7.5 billion gallon annual target established by the federal Renewable Fuels Standard (RFS) adopted in 2005 (the latter policy calls for 5 percent of total U.S. gasoline demand to be met using renewable fuels by 2012). Long-term projections taking into account cost, feedstock supply, and other constraints do not, however, foresee corn-based ethanol production exceeding 15–20 billion gallons annually.

- The current ethanol boom is affecting practically every aspect of U.S. agriculture. In 2007, the nation's farmers planted a record corn crop, increasing corn acreage by 19 percent. Additional land in corn production largely came from shifting acreage out of soybean production. As a result of strong demand, corn prices have not only remained high but are driving up prices for other commodity crops.

- Consumer food prices are not expected to be severely affected by high corn prices resulting from the current ethanol boom. Nevertheless, higher feed costs increase consumer prices for poultry, eggs, and red meats. This will likely cause overall retail food prices to rise somewhat faster than the general rate of inflation rate through the end of the decade (2008–2010). After these near-term price adjustments, however, consumer food prices are expected to rise more slowly than the general rate of inflation.

- Though corn-based ethanol replaces fossil fuels, its capacity to mitigate GHG emissions is limited. Taking into account the entire product life-cycle, the use of corn-based ethanol is estimated to reduce GHG emissions by roughly 10–20 percent relative to gasoline.[3] Therefore, the foreseeable expansion of corn-based ethanol production can be expected to only marginally reduce total U.S. GHG emissions (by less than 0.5 percent).

- More substantial GHG reductions (up to 80–90 percent relative to gasoline) and significantly larger production volumes could be achieved through the successful commercialization of technologies for producing ethanol from cellulosic biomass. But large-scale expansion of this capability requires technological innovations.[4]

Effects of Climate Change on Agriculture

Agriculture, especially crop production, is fundamentally linked to climatic conditions, so any changes in climate will necessarily affect agriculture. Several assessments have scrutinized the effects of alternative climate-change scenarios on the U.S. agriculture sector, and although their predictions vary (in some cases widely), there is general agreement that climate change is unlikely to materially alter the ability of the United States to feed its population and remain a strong agricultural exporter.[5]

Generally, the predicted economic impacts from climate-related effects on agriculture are positive but moderate in aggregate over about the next 30–100 years. Though projected future growing conditions (temperature,

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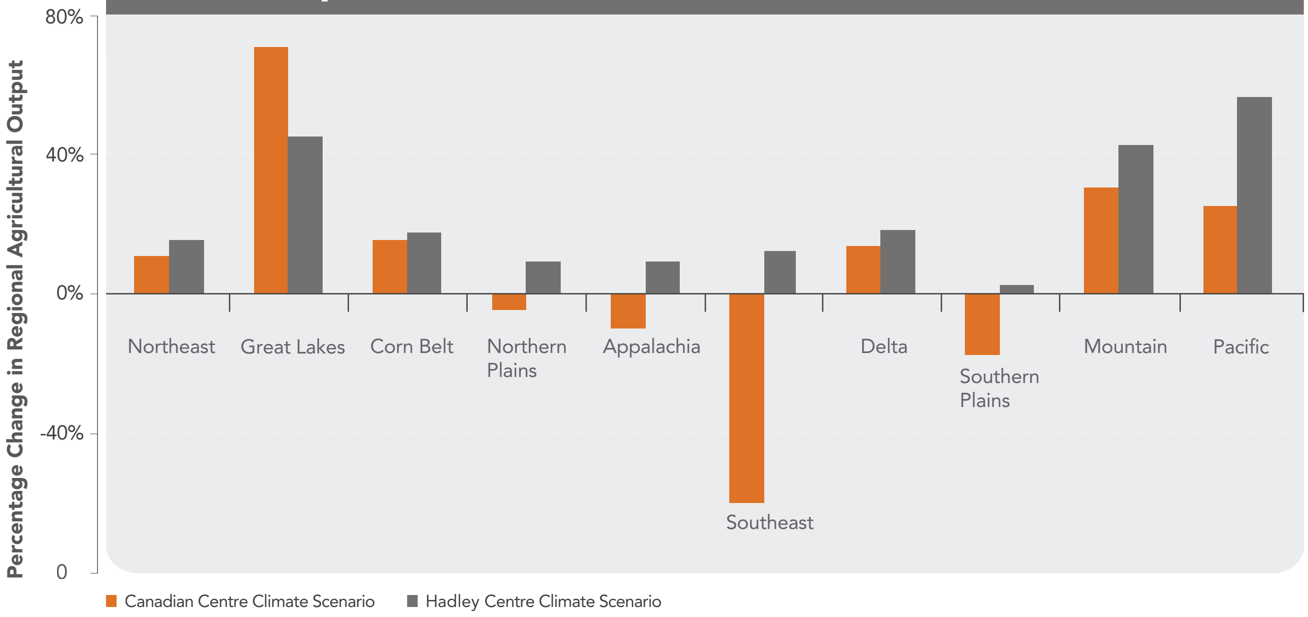
[2] As of August 22, 2007 (Renewable Fuels Association).

[3] M. Wang, M. Wu, and H. Huo, "Life-cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types," *Environmental Research Letters* 2(2007):1–13; and K. Sanderson, "A Field in Ferment," Nature 444, Business Feature, 673–676, 7 December 2006.

[4] M. Wang, M. Wu, and H. Huo, note above.

[5] J. Reilly et al., "Agriculture: The Potential Consequences of Climate Variability and Change for the United States," in US Global Change Research Program, *US National Assessment of the Potential Consequences of Climate Variability and Change*, New York: Cambridge University Press, 2001; and R. Adams, R. Hurd, J. Reilly, *A Review of Impacts to U.S. Agricultural Resources*, Arlington, VA: Pew Center on Global Climate Change, 1999.

Figure 1 Changes in Agricultural Output under Alternative Climate Scenarios by Region: Results of the U.S. National Assessment[12]



precipitation) would affect especially crop production and its regional distribution, market adjustments in production, consumption, and trade ensure that even substantial production changes would not become very costly overall. Longer-term agricultural effects of climate change are less well understood.

For example, the U.S. National Assessment[6] examined the effects of alternative climate-change scenarios on agriculture. Depending on the adopted climate model,[7] the results ranged from moderate costs to a few billion dollars of overall benefits in agriculture.[8] Potential agricultural benefits from climate change stem from increasing temperatures and CO_2 levels, which boost crop yields.[9] While increased crop yields generally count as a benefit, the fact that higher yields tend to lower crop prices means that farmers may not be any better off and could in fact suffer losses. Of course, lower crop and food prices are a plus for consumers.[10] Targeted adaptation efforts would tend to provide positive benefits to agriculture, while increasing pest populations and other production risks associated with climate change would have negative impacts.

Notwithstanding the fact that overall effects are predicted to be moderate, regional impacts can be large. Predicted changes in temperature and precipitation are least favorable to agriculture in the South and Great Plains, where the net effect of climate change is negative (see Figure 1). Predicted losses in agricultural output are especially large in the Southeast.[11] Northern areas, on the other hand—particularly the Great Lakes area—may benefit from more favorable climatic conditions.

Though different assessments project climate-related changes in agricultural production and land prices, these changes are moderate in the context of other trends in agriculture and food markets. For example, agricultural land prices declined roughly 50 percent between 1980 and 1983—a shift that is well beyond the projected effects of climate change. On the consumer side, a recent rise in retail food prices is likely to produce more noticeable impacts than any predicted effect from climate change. Similarly, changes in world markets for

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[6] Reilly et al. note above.

[7] Two climate scenarios, the Canadian Climate Centre Model and Hadley Centre Model, were examined in the National Assessment. The Canadian model predicts significant warming in the South such that increases in the average temperature of about 9°F (5°C) are common by the year 2100. The Hadley model predicts more moderate temperature increases (Reilly et al. 2001, note 5 above).

[8] See also C. Field et al. "North America", in *"Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, et al. (Eds.), Cambridge University Press, Cambridge, UK, 617-652, 2007.

[9] Higher atmospheric CO_2 concentrations generally enhance the rate of photosynthesis, which in turn improves crop yields.

[10] Reilly et al. 2001, note 5 above.

[11] The U.S. National Assessment defines agricultural output as aggregated crop and livestock production weighted by output prices.

agricultural products, trade and agricultural policies, farming technology, or competing uses for agricultural land are likely to impact this sector more dramatically than climate change over the next several decades.

Predictions about the effects of climate change on agriculture depend critically on underlying assumptions regarding technological change, adaptation to new climatic conditions and regulatory regimes, and alternative land uses. They also depend on international developments with respect to trade, food demand, and production (which in turn are also likely to be affected by climate change). Substantial changes in any of these modeling assumptions will alter and possibly overshadow predicted effects from climate change. For example, new crop varieties are continuously developed and crops today have broader suitable geographical ranges than just a few decades ago. This technological progress will continue and may even intensify in response to climate change. Opportunities to improve crop productivity and adapt to changing conditions are also vastly improved by biotechnology.

Besides temperature changes, the full effect of climate change will depend on other factors such as precipitation (total precipitation and its temporal distribution); extreme weather events (storms, droughts, etc.); changes in pest populations, plant diseases, and weeds; and so forth. These effects are poorly predicted by current climate-change models—different agricultural assessments emphasize inherent difficulties in properly accounting for them—and each may impose important costs on agriculture.

The difficulty of predicting net effects is illustrated by examining water availability—a critically important parameter—in irrigation-dependent areas where climate change is expected to alter both crop yields and water supply. The amount of water available for irrigation will change with both the timing and volume of annual water supply. Currently, much of the precipitation in many irrigation-dependent states occurs during the winter months, whereas demand for irrigation water peaks during the late spring and summer. Two types of water storage—man-made reservoirs and mountain snow pack—smooth this temporal discrepancy in precipitation and water demand. For example, in late April, the water preserved in the snow pack of California's Sierra Nevada mountains currently just about matches what is stored by the state's major reservoirs. According to current projections, rising temperatures may well reduce snow-pack storage capacity by one-third by the middle of the century. This reduction in natural storage capacity would likely be replaceable, at least in part, by man-made storage, though at considerable cost. Without alternative storage capacity, agricultural producers in California would have to cope with a substantially reduced supply of water for irrigation.[12]

Agriculture as a Source of GHG Emissions

Emissions

Currently, the agricultural sector is responsible for about 8 percent of total U.S. GHG emissions (see Figure 2). Within the U.S. economy, emissions from agriculture rank considerably below those from the electric power industry (33 percent of total emissions), the transportation sector (28 percent of total emissions), and the industrial sector (19 percent of total emissions). The contribution from agriculture exceeds, however, the contribution from primary energy consumption in the commercial and residential sectors (6 percent and 5 percent of total emissions, respectively). In absolute terms, agricultural GHG emissions amount to about 595 million metric tons of CO_2-equivalent per year, whereas total annual U.S. emissions are about 7,260 million metric tons CO_2-equivalent.[13]

Although agriculture is not a major source of U.S. CO_2 emissions, it is the source of almost 30 percent of methane[14] emissions and 80 percent of nitrous oxide emissions (see Figure 3). Together, these two gases, while not on par with CO_2, constitute almost 15 percent (on a CO_2-equivalent basis) of all GHG emissions in the United States.

Nitrous oxide emissions from agricultural soils account for almost two-thirds of overall GHG emissions from agriculture. These emissions originate primarily from the breakdown of manure and nitrogen fertilizers, but are also released from nitrogen-fixing crops (e.g. soybeans, alfalfa, and clover). Nitrous oxide emissions from soil management constitute roughly 5 percent of all U.S. GHG emissions.

Though GHG emissions have increased during the last

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[12] Changes in the irrigation water supply undoubtedly will have considerable consequences on agriculture. Schlenker et al. examine projected climate-change scenarios for California and predict that declining water availability may reduce the value of farmland by as much as 40 percent ($1,700 per acre). This effect is due solely to lost irrigation and does not include effects from changing temperature, which the study predicts will further reduce the value of farmland. (Schlenker, W., W. M. Hanemann, and A. Fisher, 2007, Water Availability, Degree Days, and the Potential Impacts of Climate Change on Irrigated Agriculture in California, Climatic Change, 2007 81:19-38.)

[13] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–-2005," , April 15, 2007.

[14] The decomposition of livestock manure, under anaerobic conditions, produces methane. According to the U.S. Environmental Protection Agency, roughly 540 million CO_2-equivalent tons of methane were emitted from human-related activities in the United States in 2005 (EPA, note 14 above). Nearly one-third of these emissions originated in the animal husbandry industry, including enteric fermentation and manure management.

decade, emissions from agriculture have remained nearly constant. Methane from manure management is the main exception to this trend: methane emissions have increased by roughly one-third as livestock production has shifted to larger and larger concentrated animal feeding operations (CAFOs). On the other hand, large production units may facilitate future mitigation efforts by making investments in capital-intensive methane-reduction technologies, such as methane digesters, more cost-effective.

Potential for GHG mitigation and offsets

Collectively, the agriculture sector can contribute to GHG mitigation efforts in a number of ways, especially by increasing soil carbon sinks, reducing emissions of nitrous oxide and methane, and providing biomass-based alternatives to fossil-fuel use.[15] Prominent GHG mitigation strategies in agriculture include the following:

1. Improved agricultural land management to increase soil carbon storage.
2. Enhanced livestock and manure management to reduce methane emissions.

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[15] See, for example, K. Paustian, J. M. Antle, J. Sheehan, and E. A. Paul, *Agriculture's Role in Greenhouse Gas Mitigation*, Arlington, VA: Pew Center on Climate Change, September 2006.

Figure 2 U.S. Greenhouse Gas Emissions by Sector[16]

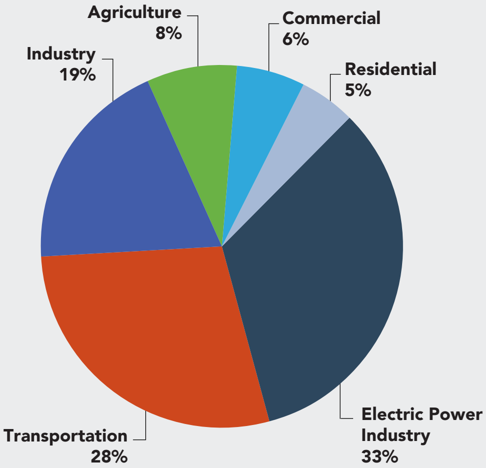
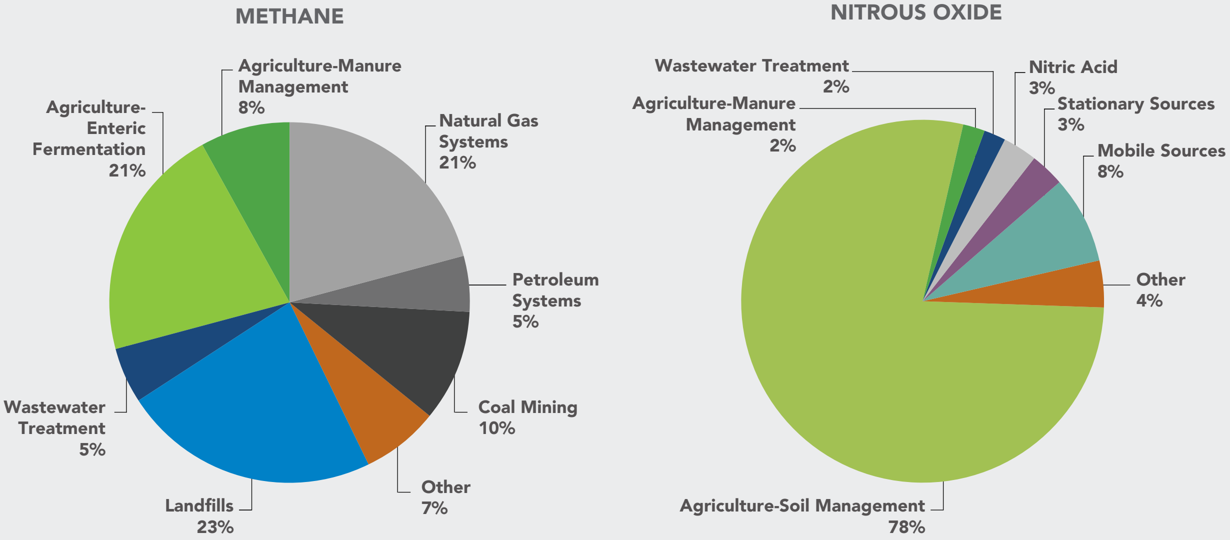


Figure 3 Methane and Nitrous Oxide Emissions in the United States, by Source[17]



3. Development of new fertilizer application techniques to reduce nitrous oxide emissions.
4. Increased use of biomass energy crops to replace fossil fuels.

Improved agricultural land management to increase soil carbon storage

Changes in land use and agricultural practices can increase the amount of carbon stored in soils. Best management practices that increase soil sequestration include adopting conservation tillage, reducing fallow periods, including hay crops in annual rotations, and producing high-residue-yielding crops. Converting lands to conservation set-asides with trees (afforestation) or perennial grasses can produce larger changes in soil sequestration than changes in agricultural practices.[16]

Management practices that increase soil sequestration can be implemented relatively quickly and in many cases at low cost relative to other forms of emissions reductions. The amount of carbon storage that would be economically competitive with other mitigation opportunities, however, is less than the total technical potential for sequestration in agricultural soils. National-level studies suggest that as much as 70 million metric tons of soil-based carbon sequestration per year are available at a cost of $50 per ton of carbon ($13 per ton of CO_2) through best management practices, and another 270 million metric tons of carbon sequestration per year could be achieved by converting agricultural lands to forests.[17]

The profitability of alternative management techniques and the amount of carbon sequestration achievable at a given price vary widely across regions. The potential to increase soil carbon storage on agricultural lands generally ranges from 0.1 to 1 ton per hectare (0.04–0.4 tons per acre) per year due to differences in soil attributes. Most studies suggest that the Midwest and Great Plains regions are well suited for conservation tillage practices, while the Southeast may be better suited for the conversion of agricultural lands to forests.

Agricultural soils do not have an unlimited capacity to store carbon, and for any given management practice a saturation point will be reached over time. Complete carbon saturation is estimated to occur 20–30 years after changes in farm management practices and 70–150 years after afforestation, depending on the tree species used. Also, carbon stored in soils can be quickly released back into the atmosphere once a farmer reverts back to traditional tilling practices. Thus, polices that provide offset credits for soil-based carbon sequestration in the context of a domestic CO_2 cap-and-trade program must be cognizant of permanence issues and of the potential for stored carbon to be released. Nevertheless, this option can provide immediate, low-cost GHG-mitigation benefits while more permanent solutions are developed.

Collectively, the agriculture sector can contribute to GHG mitigation efforts in a number of ways, especially by increasing soil carbon sinks, reducing emissions of nitrous oxide and methane, and providing biomass-based alternatives to fossil-fuel use.

Nitrous Oxide

Primary means of reducing nitrous oxide emissions focus on more efficient and moderate uses of manure and nitrogen fertilizers. This may be achieved by improving the timing and placement of fertilizers, testing soils to determine fertilization requirements, using nitrification additives, and incorporating fertilizers into soils. Technically, these practices could reduce nitrous oxide emissions from agriculture by up to 30–40 percent (reductions available at a competitive cost could be smaller). More efficient fertilizer applications would generate additional water-quality benefits by reducing nutrient runoff.

Methane

While enteric fermentation in the digestive systems of ruminant animals accounts for most agricultural methane emissions, manure management may offer greater opportunities

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[16] In 2005, U.S. agricultural soils were sequestering about 20 MMT of carbon per year with 36% of croplands applying some form of conservation tillage.

[17] K. Paustian et al., note 18 above; and J. Lewandrowski et al., *Economics of Sequestering Carbon in the U.S. Agricultural Sector,* USDA Economic Research Service, 2004.

for mitigation.[18] The main approach for controlling these emissions is to capture the methane and then burn the bio-gas to generate electricity. Other manure management options involve using manure-storage sheds, aeration processes, and lagoon storage systems with methane capture.

Using captured methane to generate electricity can reduce farm outlays for electricity and even provide surplus electricity for sale back to the grid. On-farm electricity generation produces CO_2 emissions but because of the higher global warming potential of methane, net GHG reductions—on a CO_2-equivalent basis—can approach 90 percent.[19] In addition, the electricity generated from this activity replaces other forms of electricity generation, including generation using equally or more carbon-intensive fossil fuels. In that case, net reductions are achievable even in CO_2 emissions alone.

Over the last few years, interest in methane digesters for use in animal husbandry operations has increased noticeably. Most of the potential for applying this technology is concentrated in major dairy- and livestock-producing regions, such as California, Wisconsin, Iowa, Minnesota, North Carolina, and Texas. For example, California has initiated several programs, including the Dairy Power Production Program, the Self-Generation Incentive Program, and net-metering assembly bills, to encourage manure treatment with methane digesters. The Dairy Power Production and Self-Generation Incentive Programs provide cost-share funding for capital investments in new methane digesters.[20] Assembly Bills 2228 (signed into law in 2002) and 728 (signed into law in 2005) require the state's three largest investor-owned utilities (Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric) to offer net metering to dairy farms that install methane digesters. Potential farm-level benefits from methane digestion are especially pronounced for relatively large operations, where the capital cost of installing digesters is least prohibitive, and in warm climates, where methane production potential is greatest.[21]

Total Mitigation Potential

The agriculture sector offers a wide range of mitigation opportunities. Therefore, the key question is how different options compare in total mitigation potential and cost. This question is addressed in a recent EPA analysis; Table 1 summarizes the results.[22],[23] Though this issue brief focuses on agriculture, we also present results for forestry-related activities to highlight the relative potential of alternative mitigation options.

Table 1 National GHG Mitigation Total 2010-2110, Million Metric Tons CO_2 Equivalent, Annualized Averages by Activity (EPA 2005)

Activity	$ per ton CO_2 equivalent				
	$1	**$5**	**$15**	**$30**	**$50**
Afforestation	0	2	137	435	823
Forest Management	25	105	219	314	385
Agricultural Soil Carbon Sequestration	62	123	168	162	131
Fossil Fuel Mitigation in Crop Production	21	32	53	78	96
Agricultural CH_4 and N_2O Mitigation	9	15	32	67	110
Biofuels Offsets	0	0	57	375	561
All Activities	**117**	**227**	**666**	**1,431**	**2,106**

The total potential and relative cost of different mitigation activities vary considerably. At a low carbon price ($1–$5 per ton of CO_2), agricultural soil carbon sequestration is the dominant mitigation strategy. Another activity with considerable potential at low carbon prices involves managing forests for carbon sequestration. Afforestation (establishing trees on non-forested lands) and biofuels offsets (substituting biofuels for fossil fuels) offer only moderate mitigation potential at low carbon prices, but emerge as dominant mitigation activities once prices rise above $30 per ton of CO_2-equivalent. Measures to reduce fossil-fuel use for crop production and agricultural methane and nitrous oxide emissions provide moderate mitigation capacity at all carbon prices, but their overall emissions-reduction potential is relatively small.

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[18] Over the past 20 years, methane-suppressing feed additives and more efficient feed rations have become commonplace, but these options have limited the potential to further curb emissions. However, improvements in the quality of grazing plants, nutritional supplements, animal genetics, and pasture management can lead to emissions reductions of up to 20 percent from beef cattle.

[19] Burning 1 ton of methane (equivalent to 21 tons of CO_2 if allowed to vent) yields only 2.75 tons of CO_2. For more information on policy options for methane control in livestock operations, see "Air Emissions of Ammonia and Methane from Livestock Operations: Valuation and Policy Options," Shih, J-S., D. Burtraw, K. Palmer, and J. Siikamäki. RFF Discussion Paper 06-11 (March 2006) at http://www.rff.org/documents/RFF-DP-06-11.pdf.

[20] Some federal programs can also provide cost-share funding for methane digesters. Such programs include the Environmental Quality Incentives Program (EQIP), the Conservation Innovation Grants Program (CIG), and the Conservation Security Program (CSP) (NDESC 2005).

[21] Shih, J-S et al., note 22 above.

[22] "Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture", United States Environmental Protection Agency, Office of Atmospheric Programs, Washington, DC, Report EPA 430-R-05-006, November 2005.

[23] The results of the EPA-study are by and large consistent with other studies, which have examined the cost of carbon sequestration, including (i) Lewandrowski, J., M. Peters, C. Jones, R. House, M. Sperow, M. Eve, and K. Paustian (2004) "Economics of Sequestering Carbon in the U.S. Agricultural Sector," Washington, DC: U.S. Department of Agriculture, ERS; (ii) Sedjo, R, B. Sohngen, and R. Mendelsohn (2001) "Estimating Carbon Supply Curves for Global Forests and Other Land Uses." Discussion Paper 01–19, Resources for the Future, Washington, DC.; and (iii) Stavins, R. N. (1999) "The Costs of Carbon Sequestration: A Revealed-Preference Approach," American Economic Review 89(4): 994-1009.

Overall, agricultural and forestry activities offer substantial GHG mitigation potential. Even at low carbon prices—from \$1 to \$5 per ton CO_2—these activities can provide annual net emission reductions ranging from 117 to 277 million metric tons CO_2. The cost-effective potential for emission reductions increases with carbon prices, reaching more than 2,000 million metric tons CO_2-equivalent emissions per year at a price of \$50 per ton CO_2. To put these estimates into perspective, current U.S. GHG emissions total about 6,500 million metric tons CO_2-equivalent per year.

The higher end of the carbon-price range shown in Table 1 is comparable to the range of global carbon prices thought to be necessary—based on current modeling analyses—to stabilize atmospheric CO_2 concentrations later this century. For example, it is estimated that stabilizing CO_2 concentrations in the 550 parts per million range will require carbon prices to reach \$5–\$30 per metric ton CO_2 by 2025, and about \$20–\$90 per metric ton by 2050.[24]

Challenges

Agricultural emissions are unlikely to be included in binding programs to limit GHG emissions, such as a cap-and-trade program. Extending mandatory emissions-reduction requirements to agriculture would be hampered by several challenges. Agricultural GHG emissions are generally difficult to monitor and verify. Moreover, some types of mitigation—such as carbon sequestration through alternative soil management—may not be permanent.

Despite the likelihood that agriculture would be excluded from a mandatory regulatory program, the sector provides several potentially cost-effective opportunities for CO_2 offsets. Offsets, which are emissions credits generated by sources not covered under a cap-and-trade or other mandatory regulatory program, are attractive for their capacity to expand the pool of available, low-cost emissions-reduction options. However, many of the challenges associated with including agricultural sources in a mandatory regulatory program also apply to the measurement and verification of agricultural offsets. Common performance criteria for crediting offsets require that emissions reductions are real, additional, and permanent.[25] Each category of potential agricultural GHG-mitigation strategies faces difficulties in satisfying these criteria.

For example, the amount of carbon sequestered in agricultural soils is difficult to measure. Each soil type is different in its capacity to absorb (or release) carbon, and different soils have different saturation points beyond which sequestering additional carbon is not possible or requires radical changes in land use (for example, afforestation). Carbon sequestration also raises questions about permanence; changes in soil management practices can quickly release the sequestered carbon back into the atmosphere. Leakage issues are also potentially difficult: if changing soil management practices to enhance sequestration in one field means that countervailing changes occur in another field, no net sequestration of carbon may result.

Similar challenges arise in the context of non-CO_2 agricultural emissions. For example, nitrous oxide emissions from agricultural soils are affected not only by soil management and fertilization, but also by natural processes—nitrification and denitrification—which can vary depending on the types of soils farmed and crops grown. Measuring changes in these emissions is therefore inherently difficult. Similar issues must be resolved when crediting offsets for methane control in manure management and livestock operations.

Present programs and proposals related to agricultural offsets

Several emissions-trading markets with distinct policies regarding agricultural offsets currently exist or are in the process of being developed. For example, the European Climate Exchange excludes any offsets from agricultural sinks. The Chicago Climate Exchange, the only voluntary emissions trading market in North America, includes the National Farmer's Union Carbon Credit Program, which allows farmers to aggregate marketable carbon credits for carbon sequestering practices.[26] The Northeast and Mid-Atlantic states' Regional Greenhouse Gas Initiative (RGGI), a first mandatory cap-and-trade program to limit power-sector CO_2 emissions in the United States, includes credits for methane mitigation from manure management practices.[27] The California legislature is developing a statewide cap-and-trade system under Assembly Bill 32 (passed in 2007) but has not yet set up a framework for GHG offsets.

Some proposals for federal climate change legislation have included the agriculture sector. For example, the McCain-Lieberman "Climate Stewardship Act of 2005" and the Waxman "Safe Climate Act of 2006" both propose that emissions trading markets allow farmers to earn credits from

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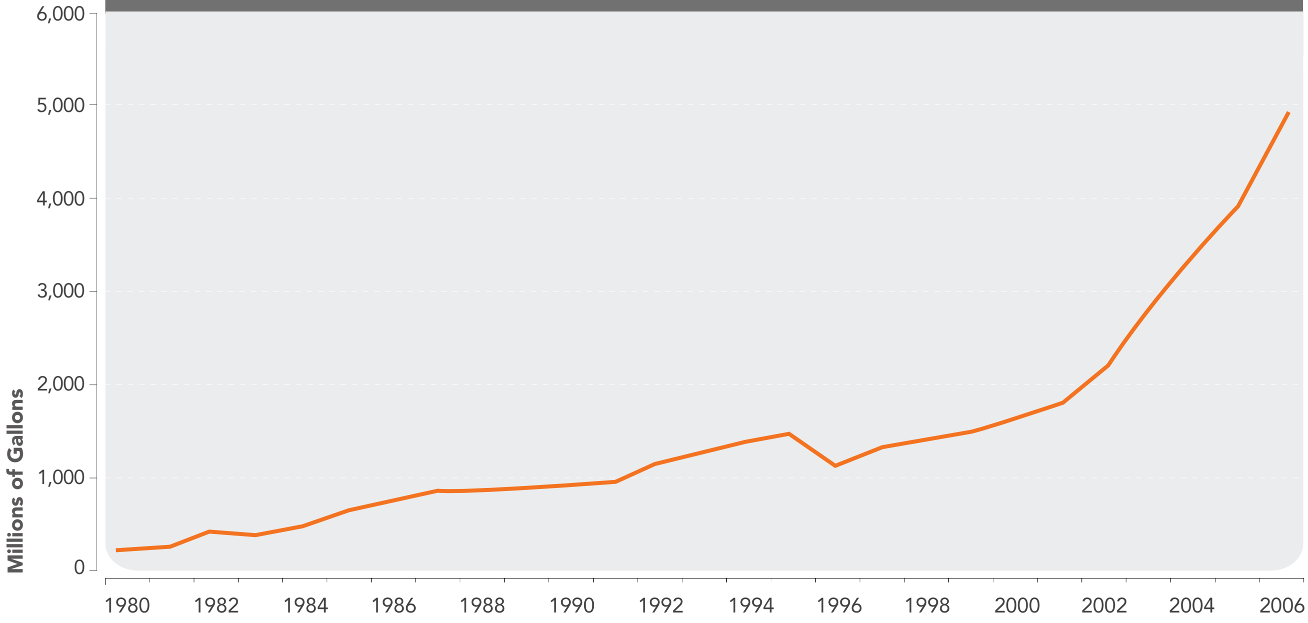
[24] Recent studies of the carbon prices required for long-term stabilization of atmospheric CO_2 are summarized in Issue Brief #2 on stabilization scenarios.

[25] For more discussion related to offsets, see Issue Brief #15.

[26] National Farmer's Union, Carbon Credit Program, 2007 http://www.nfu.org/issues/environment/carbon-credits/ (accessed July 12, 2007).

[27] The Climate Trust, RGGI Eligible Sector 4: Avoided Methane Emissions from Agricultural Manure Management, 2007, http://climatetrust.org/solicitations_RGGI3.php (accessed July 12, 2007).

Figure 4 U.S. Fuel Ethanol Production 1980-2006, Annually (Renewable Fuels Association)



carbon storage in agricultural soils.[28] However, the amount of offsets permitted in these bills is limited, and no federal legislation has considered credits from agricultural activities that mitigate nitrous oxide or methane emissions.

Biofuels

U.S. production of ethanol has skyrocketed in recent years—approximately quadrupling since 2000/2001 (Figure 4)—and is poised to double again by the year 2008. According to the Renewable Fuels Association, nearly 130 ethanol biorefineries with total annual production capacity of 6.7 billion gallons nationwide were in operation as of late August 2007.[29] The nearly 80 additional biorefineries currently under construction are expected to approximately double present ethanol production capacity.[30] With the recent expansion of corn-based ethanol production, the United States has become the world's largest producer of ethanol, surpassing Brazil's sugarcane-based ethanol production.[31]

With more than 13 billion gallons of annual production capacity either already in operation or under construction, ethanol consumption in the United States is poised to far exceed the 7.5 billion gallon per year target established by the 2005 Renewable Fuels Standard (which calls for domestic renewable fuels to displace five percent of total U.S. gasoline demand by 2012).

Several factors have contributed to the rapid expansion of ethanol production in the United States. During the last year, relatively high oil prices combined with a 51-cent per gallon tax credit to make ethanol economically attractive; at the same time, demand for ethanol as a substitute for the fuel oxygenate MTBE was growing. More broadly, policymakers view increased use of biofuels as a means of enhancing America's energy security by reducing dependence on fossil fuels. Strongly increased demand for ethanol is almost fully supplied from domestic sources; overseas suppliers are deterred by a 54-cent per gallon tariff on ethanol imports.[32]

Corn prices roughly doubled during the last year, yet demand for corn remains strong.[33] U.S. producers have responded

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[28] Evan Branosky, WRI Policy Note 1, World Resources Institute, 1–6, 2006.

[29] http://www.ethanolrfa.org/industry/locations/

[30] U.S. production of biodiesel—another principal biofuel and a substitute for diesel—is small relative to ethanol. In 2006, about 250 million gallons of biodiesel were produced in the United States.

[31] In 2006, the United States. and Brazil produced more than 70% of world's total ethanol production (13.5 billion gallons). U.S. ethanol is corn based; Brazilian ethanol is derived from sugarcane.

[32] However, ethanol imports from designated Central American and Caribbean countries are duty-free for up to 7% of the U.S. ethanol markets.

[33] See, for example, A. Baker, and S. Zahniser, Ethanol Reshapes the Corn Market, *Amber Waves*, Vol. 4,

Corn-based ethanol reduces GHG emissions, but not necessarily by much. Researchers recently estimated that corn ethanol, produced using current technology, reduces GHG emissions on average by 19 percent for every gallon of gasoline displaced.

to these new market conditions surprisingly swiftly; the 2007 corn crop is the largest corn crop planted in more than 60 years.[34] In acreage planted, the 2007 crop—at 92.9 million acres—exceeds the 2006 crop by 19 percent. The increase in corn acreage has been offset by shifting land out of soybean production; soybean acreage declined 15 percent from 2006 to the 2007 total of 64.1 million acres.[35] The recent, dramatic increase in corn acreage has somewhat reduced corn futures prices, though futures prices continue to reflect expectations of strong demand growth going forward. Market adjustments to the rapid expansion of corn-based ethanol production also extend beyond corn itself, trickling through the entire U.S. agricultural and food sectors.

Given current average yields of about 2.8 gallons of ethanol per bushel of corn and 150–160 bushels of corn per acre, every additional billion gallons of ethanol production implies about 2.2–2.4 million acres of additional land devoted to corn. Thus, increasing corn-ethanol production by another 6 billion gallons per year implies an additional land requirement of 13–14 million acres. Farmers' response this year (nearly 15 million additional acres of corn) seems to roughly uphold the current demand-supply balance. The fact that farmers are planting mostly bioengineered corn (a 12 percent increase from 2006) will also help supply keep pace with demand.

Replacing fossil fuels with corn-based ethanol reduces GHG emissions, but not necessarily by much. After thoroughly examining life-cycle GHG emissions for gasoline and ethanol, researchers at Argonne National Laboratory[36] recently estimated that corn ethanol, produced using current technology, reduces GHG emissions on average by 19 percent for every gallon of gasoline displaced.[37] The study highlights the importance—from the standpoint of GHG emissions—of the process fuel used in ethanol production. Ethanol produced at plants that are fueled by natural gas can achieve GHG reductions of 28–39 percent compared to gasoline. Switching from natural gas to coal as the process fuel, however, may completely eradicate the GHG reduction benefits of ethanol. Although most current ethanol plants run on natural gas, this finding is important because high natural gas prices are encouraging developers to opt for a coal-fueled ethanol production process at new plants. Other well-known, but perhaps less inclusive assessments have suggested yet lower GHG reductions from corn-based ethanol—around 7–12 percent relative to gasoline.[38]

Despite their slight differences, the results from available assessments all suggest that increasing corn-based ethanol usage to 12–14 billion gallons annually (enough to displace nearly 10 percent of U.S. gasoline demand) would reduce present GHG emissions only minimally—by merely a fraction of a percent. Until it becomes technologically and economically feasible to produce cellulosic ethanol, which has the potential to cut GHG emissions by 80–90 percent relative to gasoline, the current ethanol boom seems unlikely to provide significant climate benefits.[39]

Specific provisions in the new U.S. Department of Agriculture (USDA) 2007 Farm Bill proposal would support further expansion of the domestic biofuels industry, including a total of $1.6 billion directed toward renewable energy and

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Issue 2, 2006 (updated May 2007), http://www.ers.usda.gov/AmberWaves/May07SpecialIssue/Features/Ethanol.htm.

[34] National Agricultural Statistics Service, "U.S. Farmers Plant Largest Corn Crop in 63 Years," News Release, June 29, 2007, Washington, DC: U.S. Department of Agriculture.

[35] Soybeans and corn are often planted in rotation. Recent increases in corn acreage often involves farmers shifting from corn-soybean rotation to corn-corn-soybean rotation.

[36] M. Wang et al., note 3 above.

[37] Cellulosic ethanol would offer more significant GHG emission reductions (up to 80–90 percent, similar to GHG reductions from the sugarcane-based ethanol in Brazil), but cellulosic ethanol production is currently not economically feasible.

[38] A. E. Farrell, R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare, and D. M. Kammen, "Ethanol Can Contribute to Energy and Environmental Goals, *Science* 311 (27 January 2006): 506–508; and J. Hill, E. Nelson, D. Tilman, S. Polasky, and D. Tiffany, "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences* 103, no. 30 (July 25, 2006): 11206-11210.

[39] Studies by M. Wang et al. (note 3 above) and Farrel et al. (note 41 above) also address the long-standing dispute about whether the fossil-energy balance of corn ethanol is positive—that is, whether the use of corn ethanol results in a net reduction of fossil-fuel use, taking into account upstream fossil-fuel inputs to grow, harvest, and process corn into ethanol. For example, Wang et al. find that all current and potential future ethanol production processes achieve a positive fossil-energy balance. The energy balance of gasoline, on the other hand, is negative. Farrel et al. reaches similar conclusions.

cellulosic ethanol projects. Other measures in the 2007 Farm Bill proposal include $500 million for bioenergy and biofuel research, $500 million to support rural renewable energy systems, and $210 million to support loan guarantees for cellulosic ethanol projects.

From farmers' perspective, the effects of the ethanol boom are somewhat mixed. Crop producers benefit: high prices and increased demand for corn strengthen other crop prices and agricultural land values. Livestock producers, however, face increased feed prices. Distiller grains, a byproduct of ethanol production, can be used as feed for beef cattle, but poultry and pork production are especially affected by rising corn costs. Nevertheless, USDA expects overall farm incomes to remain strong, in large part due to corn-based ethanol. Higher commodity prices also reduce budget expenses for price-dependent Farm Bill programs and allow agricultural producers to rely on the market for a greater share of their income.

Consumer prices are not expected to be severely affected by the expansion of corn-based ethanol production. Higher feed costs are projected to increase consumer prices for poultry, eggs, and red meats; hence, overall production of these agricultural products may decline slightly. Overall, USDA projects that retail food prices will rise between 2008 and 2010 at a rate moderately faster than the general inflation rate. After these near-term price adjustments, however, consumer food prices are expected to rise more slowly than the general rate of inflation.[40], [41]

Notwithstanding the current boom, growth in the corn-ethanol industry is expected to slow down and then level off. Though annual ethanol production may soon exceed USDA's 10-year baseline projection of 12 billion gallons, long-term corn-ethanol production is not expected to rise beyond 15–20 billion gallons annually. At that level, land requirements for corn cultivation would approach 100 million acres, of which nearly half would be needed to supply corn for the ethanol industry.[42]

An important issue is how the ethanol and agricultural commodity markets will respond to production shortfalls due to weather, pests, and other factors. Ethanol production, which is on track to account for more than 30 percent of U.S. corn consumption in the near future, is less responsive to the price of corn than other major markets (e.g. for feed uses and exports). As a result, overall demand for corn is likely to become less responsive to prices and larger price changes are likely to follow market adjustments in case of production shortfalls. These effects are magnified by a decline in corn stocks, which have diminished due to strong demand and currently provide only a limited buffer for potential supply shocks. Therefore, the agricultural sector is likely to experience higher overall prices and increased market volatility.[43]

Cellulosic ethanol, though not yet economically competitive, could substantially expand the potential of biofuels. For example, the "billion-ton" study by USDOE and USDA concluded that U.S. agricultural and forestry lands have the resource potential to produce more than one billion tons of biomass per year by the mid-21st century, assuming historically strong productivity improvements continue.[44] This represents potentially adequate feedstock to support 110 billions of gallons of cellulosic-ethanol production per year. Currently, the technical potential of agricultural biomass is about 194 million dry tons per year (enough to support 15 billion gallons of ethanol output). However, significant technological advances are needed to convert this technical potential to economically attractive production.

Finally, continued expansion of the biofuels industry and strong crop prices are bound to have a range of land-use consequences. For example, strong demand for corn has already raised concerns that environmentally sensitive lands in the Conservation Reserve Program (CRP)[45] will be returned to crop production. This, in turn, could have potentially adverse implications for soil conservation, carbon sequestration, and other environmental aspects of agriculture. Future expansion of cellulosic ethanol production may generate similar externalities, and may extend to forested areas.[46] On the other hand, crops such as alfalfa or switch grass, which require less intensive farming practices than corn and other cash crops, may provide feedstock for cellulosic ethanol production while also generating environmental benefits from, for example, reduced soil erosion.

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[40] USDA Economic Research Service, *Agricultural Baseline Projections: U.S. Crops,* 2007–2016, Washington, DC: USDA, 2007.

[41] Westcott, P. R. *Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?* USDA Economic Research Service, Washington, DC: USDA, 2007.

[42] USDA Economic Research Service and The Office of Chief Economist, An Analysis of the Effects of an Expansion in Biofueld Demand on U.S. Agriculture. Washington DC: USDA May 2007.

[43] Westcott, et al. note 44 above.

[44] USDOE and USDA, "Biomass as a Feedstock for Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Supply," U.S. Department of Energy and U.S. Department of Agriculture. Washington DC, April 2005.

[45] The Conservation Reserve Program financially encourages farmers to convert highly erodible cropland or other environmentally sensitive land to vegetative cover, such as native grasses, trees, filterstrips, or riparian buffers. Farmers receive an annual rental payment for the term of the multi-year contract. CRP goals include reducing soil erosion, improving water quality, establishing wildlife habitat, and enhancing forest and wetland resources.

[46] Sugar-based ethanol production in Brazil already has triggered concerns about increased deforestation. However, the productivity (gallons per acre) of Brazilian sugar-based ethanol production is high, and the acreage required for ethanol is lower than in the United States. Also, Amazonian rainforests, where deforestation is a major concern, are not fit for growing sugarcane. Therefore, ethanol-based deforestation, if any, would primarily be due to secondary effects such as overall increases in crop, feed, and land prices.

ISSUE BRIEF 14

MANDATORY REGULATION OF NONTRADITIONAL GREENHOUSE GASES: POLICY OPTIONS FOR INDUSTRIAL PROCESS EMISSIONS AND NON-CO_2 GASES

DANIEL S. HALL

MANDATORY REGULATION OF NON-TRADITIONAL GREENHOUSE GASES: POLICY OPTIONS FOR INDUSTRIAL PROCESS EMISSIONS AND NON-CO$_2$ GASES

Daniel S. Hall

SUMMARY

Traditional economic theory suggests that the most efficient and least-cost approach for regulating greenhouse gas (GHG) emissions will be as broad as possible—covering as many emissions from as many sources as possible under a single pricing policy designed to elicit the cheapest abatement options. Applying this concept is relatively straightforward for the dominant GHG, carbon dioxide (CO$_2$). CO$_2$ emissions from the use of fossil fuels account for around 80 percent of U.S. GHG emissions[1] and are well-suited to regulation through either an emissions tax or cap-and-trade program.[2] A wide variety of other emissions sources and gases account for the other approximately 20 percent of U.S. GHG emissions.[3] Some of the cheapest mitigation options are likely to involve these "non-traditional" GHGs,[4] making it desirable to include them in a regulatory program. Given the diversity of activities and sources that give rise to these emissions, however, creative policy approaches may be needed to effectively tap associated abatement opportunities.

This issue brief surveys options for regulating those non-traditional GHG emissions that lend themselves most readily to a mandatory approach, including methane emissions from coal mines, nitrous oxide and process CO$_2$ emissions from large stationary sources, and emissions of high global-warming potential (GWP) fluorinated gases. Together this group of emissions and sources accounted for about 5.5 percent of the overall U.S. GHG inventory in 2005. As discussed in more detail in Issue Brief #1, many other non-traditional GHG emissions originate from fugitive sources that would be difficult to include in a mandatory program. These emissions are likely best addressed through a project-based program to recognize offset activities as part of a broader tax or cap-and-trade program.[5]

Among the gases covered in this issue brief as potential candidates for inclusion in a mandatory program, some could be integrated relatively easily in a cap-and-trade (or tax) program; others could be included, but special considerations or provisions may need to apply; and others still may need to be addressed through sector-specific policies or through efficiency or technology standards.

- The fluorinated gases could be included in a mandatory program by regulating production sources rather than actual emissions, which are widely dispersed and difficult to measure. The number of entities

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[1] All emissions data in this issue brief are from 2005 and are taken from a report issued by the U.S. Environmental Protection Agency. U.S. EPA, 2007. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA 430-R-07-002, EPA: Washington, DC. Available at http://epa.gov/climatechange/emissions/usinventoryreport.html Accessed August 21, 2007. Fossil fuel combustion accounted for 79 percent of U.S. GHG emissions in 2005; the non-energy use of fossil fuels—as lubricants or feedstocks, for example—accounted for another 2 percent.

[2] See Issue Brief #5 on taxes, trading schemes, and standards for further discussion of these regulatory approaches.

[3] See Issue Brief #1 on U.S. GHG emissions for a detailed breakdown of these emissions.

[4] For example, an EIA analysis from March 2006 that considered a range of cap-and-trade proposals found that with modest near-term GHG permit prices ($8 to $24 (2004 dollars) per metric ton of CO$_2$e in 2020), reductions in other GHGs (i.e., those besides energy-related CO$_2$) would account for 25–55 percent of total emissions reductions in 2020, despite composing only about 6 percent of regulated emissions in the reference scenario. (EIA, 2006. *Energy Market Impacts of Alternative Greenhouse Gas Intensity Reduction Goals*, SR/OAIF/2006-01, EIA: Washington, DC.)

[5] Offset programs are discussed in Issue Brief #15. Such programs could be used to recognize GHG reductions that involve fugitive emissions, such as methane and nitrous oxide emissions from agricultural activites (over 7 percent of U.S. emissions) and from landfill and wastewater treatmeant (over 2 percent). (See Issue Brief #13 for further information on specific GHG-reduction opportunities in the agricultural sector.) Some non-traditional GHG emissions may be difficult to regulate under any policy, such as methane emitted during the transmission, storage, and distribution of natural gas (around 1 percent of U.S. GHG emissions) or nitrous oxide from mobile combustion (around 0.5 percent of U.S. GHG emissions).

engaged in producing or importing these gases, however, is comparatively small. Fluorinated gases could be included in an economy-wide tax or cap-and-trade program; alternatively, they could be addressed in a separate, stand-alone cap-and-trade (or price-based) program.

- Industrial process emissions from large stationary point sources—where measurement is straightforward—can generally be included in broad tax or cap-and-trade programs. This category of emissions includes process-related CO_2 emissions from industrial sources and nitrous oxide (N_2O) emissions from stationary combustion and nitric and adipic acid production.
- Methane (CH_4) emissions from underground coal mines could generally be included in broad tax or cap-and-trade programs, as methane is typically vented from underground mines at a limited number of defined points. By contrast, methane emissions from surface coal mines, which occur as the coal is exposed, and from abandoned mines are fugitive in nature and probably could not be included in a mandatory price-based program. These emissions would likely be best addressed through offset programs.

Remaining sections of this issue brief describe major sources of emissions in each of these categories and outline potential policy options for addressing them.

Fluorinated gas emissions

The fluorinated gases—also frequently called the high global-warming potential (GWP)[6] gases—include three of the six traditional major GHGs: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).[7] They currently account for around 2.2 percent of total U.S. GHG emissions. Their share of total U.S. emissions has grown over the last several years, a trend that is projected to continue in the near future.[8] The vast majority of fluorinated-gas emissions originate from widely dispersed end-use activities—frequently as fugitive emissions or leaks—rather than from large point sources. This implies that regulating the original production sources for these chemicals—a relatively small number of entities—is likely to be the only practical approach to including them in a mandatory policy.[9]

Among the fluorinated gases, HFCs are most commonly used as refrigerants—in mobile and stationary air conditioning or commercial refrigeration systems, for example. They are also used as fire suppressants and as blowing agents in foam production. The majority of emissions come from leaks in air conditioning and refrigeration units. PFCs are used in semiconductor production; they are also associated with aluminum production. SF_6 serves as an insulator and interrupter in equipment that transmits and distributes electricity, and it is also used in magnesium production. Most SF_6 emissions are fugitive releases, such as leaks from gas-insulated electrical substations through equipment seals or releases during servicing or disposal activities. As noted previously, the major proposals for addressing these fluorinated-gas emissions involve regulating production, either by including production sources in an economywide pricing policy, by establishing a separate cap-and-trade system for these emissions, or by utilizing a deposit-refund approach. Each of these options is discussed at greater length below.

Include fluorinated-gas production sources and imports in an economywide cap-and-trade (or tax) program

Many cap-and-trade proposals currently under discussion would include the high GWP gases from all production and import sources (including gases embedded in imported goods).[10] Producers and importers would be required to submit allowances (on a CO_2-equivalent basis) for HFCs, PFCs, and SF_6. To provide incentives for recovering and recycling or destroying these gases, entities would be awarded allowances (or offset credits) for capturing and destroying existing stocks of these chemicals. This approach would have several benefits: it would make higher GWP products relatively more expensive[11] than alternatives with lower GWPs, driving the

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[6] Global warming potentials (GWPs) are factors that are used to calculate CO_2 equivalent units so as to facilitate comparisions between various GHGs based on the warming impact (radiative forcing) different gases have once in the atmosphere. The GWP of a gas depends on the strength of its warming effect and its lifetime in the atmosphere. HFCs and PFCs all have potent warming effects and many have long lifetimes, resulting in GWPs that range from more than 100 times that of CO_2 to more than 10,000 times greater over a 100-year period (with the most commonly used gases having GWPs ranging from 1,300 to 4,000). (IPCC/TEAP, 2005. *IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons, Summary for Policymakers,* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.) SF_6 is the most potent GHG covered by the Kyoto Protocol, with a 100-year GWP of 23,900.

[7] These are the six gases listed in the Kyoto Protocol.

[8] Both recent emissions growth and future growth projections are driven primarily by the substitution of these gases into a variety of applications, rather than from increased demand for refrigeration and other end-use activitities. Specifically, HFCs and PFCs are being used to replace ozone-depleting substances, such as CFCs, HCFCs, and halons, as these are phased out under the Montreal Protocol. For further information on projected emissions see U.S. EPA, 2006. Global Anthropogenic Non-CO2 Greenhouse Gas Emissions: 1990-2020. USEPA: Washington, DC. Available at http://www.epa.gov/nonco2/econ-inv/international.html Accessed September 18, 2007.

[9] The one notable exception involves emissions of HFC-23 from production point sources during the manufacture of HCFC-22; this source accounts for about 10 percent of fluorinated gas emissions in the U.S. These emissions would presumably be included in the regulatory program "at the smokestack" in the manner of traditional air pollutants.

[10] Because emissions of high GWP gases are associated with their use (instead of production) it is vital to include all import sources, including the high GWP gases embedded in imported goods. Failure to include imports would create a large potential source of emissions leakage. For examples of current proposals see the Lieberman-McCain "Climate Stewardship and Innovation Act of 2007" (S. 280) or the Bingaman-Specter "Low Carbon Economy Act of 2007" (S. 1766). The Bingaman-Specter legislation explicitly includes the high GWP gases in imported products (e.g., window air conditioning units).

[11] A simple calculation helps to provide a rough sense of the scale of the price incentive created by the inclusion of high GWP gases in a cap-and-trade program. Suppose the price for a metric ton of CO_2 emissions is $10. (This would translate into approximately 10 cents per gallon of gasoline.) One of the most commonly used refrigerants, HFC-134a—which has a relatively low GWP (for a fluorinated gas) of 1300—would therefore have an extra price of $13,000 per metric ton, or just under $6 per pound. Assuming that a vehicle air-conditioning unit holds around 2 pounds of refrigerant, there would be around $12 of value in completely capturing the evacuated refrigerant when the system was recharged. Incentives would be proportionally larger for higher GWP gases and higher CO_2 prices.

near-term adoption of more climate-friendly substitutes in applications where fluorinated gases are currently used. Industry would also face incentives to innovate in developing new chemicals that could perform the same functions with less warming impact. A price signal would also reward owners of more efficient equipment, such as air conditioners, and would encourage the adoption of increasingly efficient units. As already noted, incentives would also exist for the collection and recycling or destruction of existing stocks.[12] Both this approach and the next—creating a separate cap-and-trade system for only high GWP gases—have been suggested by a major producer of refrigerants as possible approaches for regulating this category of emissions.[13]

Because the fluorinated gases have such high GWPs, a potential downside to including them in an economywide approach is that relatively modest prices for CO_2 emissions could produce big changes in the cost of these chemicals.[11] In response, users might shift to alternative materials that generate other health or environmental risks (for example, the use of ammonia as a refrigerant).[14] There is also concern that a particularly sudden increase in prices might unnecessarily burden both producers and end users. A more gradual change in price would give producers time to create lower-GWP alternatives and give consumers time to acquire new equipment that uses lower-GWP alternatives, uses existing gases more efficiently, or is less prone to leakage.[15] Under a cap-and-trade system, allowance allocation could be used to ameliorate potential price shocks by awarding free allowances to the producers of fluorinated gases using an updating output-based approach, although this would tend to reduce overall program efficiency.[16]

Create a separate cap-and-trade program

Another possible approach would be to create a separate, stand-alone cap-and-trade program explicitly for the high GWP gases. This would work in a nearly identical fashion to the first approach, but it would offer the option of applying a different price to fluorinated-gas emissions (and thereby addressing the cost concerns noted above).[17] The chief disadvantage of this approach is that it produces a less efficient (and hence more costly) policy overall. Two programs with separate prices imply that society is paying more to achieve reductions in one sector than in another sector, even when those reductions achieve the same environmental benefit. Other disadvantages are more political: once one sector receives a special carve-out, others may line up for theirs. If separate treatment of the fluorinated gases begins to undermine a unified, economywide approach, policy costs and efficiency losses would rise further. In addition, the potential for disruptive levels of price volatility rises under smaller, separate trading programs. Finally, all of these disadvantages also extend into the future: a lower near-term price for fluorinated-gas emissions—one designed to avoid hardship—would also lower the effective incentives for innovation to develop alternative chemicals. To help address some of these disadvantages while still attending to short-term price concerns, one might design a separate program for fluorinated gases such that it gradually converges to, and eventually links with, an economywide policy. In summary, the overall economic cost and political difficulties of a separate cap must be weighed against society's interest in tailoring regulation and managing price increases in this sector.

Use a deposit-refund approach

A third regulatory option would be to institute a deposit-refund program in which an up-front fee is charged for the production (or initial purchase) of fluorinated gases that is refunded when the gases are later captured and destroyed. This would be similar to a separate cap-and-trade program for only the high GWP gases, except that it fixes the price rather than the quantity of emissions allowed—indeed, it would be effectively identical to an emissions tax on these gases. By setting the fee and rebate amount, policymakers could make a direct decision about the level of cost that would be imposed on users of these gases. As with a separate cap-and-trade program, however, this approach would still have

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[12] This approach would also provide regulators with a potential avenue for addressing existing stocks of hydrochlorofluorocarbons (HCFCs), which currently exist in a kind of regulatory limbo between the Montreal and Kyoto Protocols. HCFCs are now being used as replacements for chlorofluorocarbons (CFCs) and other halons under the Montreal Protocol because they have less impact on stratospheric ozone. They are still ozone-depleting substances, however, and their production is being phased out under the Montreal Protocol. They are also—like other fluorinated gases—potent greenhouse gases, but because they were already regulated under the Montreal Protocol they were not included in the Kyoto Protocol. The former agreement, however, regulates the *production* of ozone depleting substances, whereas the Kyoto Protocol is focused on *emissions* of GHGs. This means that HCFCs produced legally under the Montreal Protocol are otherwise unregulated. While there is little HCFC production in the United States that results in emissions—the bulk of U.S. production is for chemical feedstocks to make materials such as Teflon(RT)—the United States does import HCFCs in ready-to-use equipment such as window air conditioning units. Further, there are existing stocks of HCFCs in older equipment. All major Congressional proposals for comprehensive mandatory climate legislation to this point have focused on the six Kyoto Protocol gases; none have included other gases (whether HCFCs or others). By allowing existing stocks of HCFCs to qualify for project-based credits—while leaving the Montreal Protocol to address HCFC production—regulators could provide incentives for collecting and destroying HCFC stocks, to the benefit of both the ozone layer and the climate.

[13] Testimony of Mack McFarland, Committee on Oversight and Government Reform, U.S. House of Representatives, May 23, 2007.

[14] Note that an economy-wide policy would capture all potential trade-offs in terms of climate benefit. For example, switching to refrigerants with lower GWPs would be beneficial, on the one hand, but could also reduce the efficiency of refrigerant-using equipment, such as air conditioners. The result could be an increase in energy use and CO_2 emissions that would offset some of the benefits from switching refrigerants. A broad cap-and-trade or tax policy with a single emissions price will efficiently balance these emissions trade-offs. Other non-climate externalities that might be associated with switching to lower-GWP products, however, will not be captured by a climate policy (economy-wide or otherwise); correcting these externalities requires other, appropriately targeted health, safety, or environmental regulations, or other policies.

[15] The situation is analogous to having an initially modest CO_2 price that rises through time in order to avoid prematurely retiring existing capital while providing incentives for investment in less emitting technologies when it is replaced.

[16] Updating, output-based allocations can reduce product prices because they reward producers with valuable emissions allowances for each additional unit of output. Producers thus face incentives to boost output, which lowers product prices. Updating, output-based allocations entail efficiency costs because, by lowering output prices, they diminish incentives for end-use demand reductions. Potentially this allocation approach could be adopted initially to manage short-term price impacts and then be phased out over time in favor of allocation methodologies that do not entail similar efficiency losses. Policymakers will have to decide how to balance the trade-off between reducing sudden price impacts on fluorinated gases and sacrificing some program efficiency. See Issue Brief #6 for further discussion of these and other issues related to allowance allocation.

[17] A similar cap-and-trade system is currently in place for manufacturers of ozone-depleting substances under Title VI of the Clean Air Act. See http://www.epa.gov/Ozone/title6/phaseout/index.html Accessed September 19, 2007.

the disadvantage that it forecloses the opportunity to make cost trade-offs with reductions in other sectors—with resulting efficiency losses for the overall policy and higher costs for society as a whole.

Nitrous oxide and process-related CO_2 emissions from large stationary sources

Several industrial processes emit non-traditional GHGs—particularly nitrous oxide and CO_2 process emissions—at large stationary sources. Process-related CO_2 emissions from industrial sources are separate from (and occur in addition to) the CO_2 emissions associated with fossil-fuel use. For example, cement production begins by heating limestone—calcium carbonate ($CaCO_3$)—to produce lime and CO_2 (the lime goes on to form the primary ingredient in cement). Iron is produced by reducing iron ore in a blast furnace with metallurgical coke, a process that emits CO_2. Other CO_2-emitting industrial processes include ammonia production, lime production (for uses besides cement), and the production of various metals, including aluminum, zinc, and lead.[18] Industrial process-CO_2 emissions represent about 2 percent of total U.S. GHG emissions, with iron and steel production and cement manufacture accounting for the majority of these emissions.

Nitrous oxide (N_2O) emissions from stationary sources in the United States come primarily from the production of nitric and adipic acids and from combustion sources.[19] Nitric acid production plants use either non-selective catalytic reduction or selective-catalytic reduction to control emissions of nitrogen oxides (NO_x), a criteria air pollutant regulated under the Clean Air Act. In addition to controlling NO_x emissions, non-selective catalytic reduction units are also effective at controlling nitrous oxide emissions but are used in only about 20 percent of plants because of their high energy costs.[20] The other significant stationary sources of nitrous oxide are adipic acid production facilities and large combustion point sources, primarily electric power generation units. Nitrous oxide emissions from adipic acid production can be controlled using conventional pollution control technology.[21] Emissions from stationary combustion are influenced by air-fuel mixtures, combustion temperatures, and the pollution control equipment employed. Altogether stationary sources of nitrous oxide emissions account for about 0.5 percent of total U.S. GHG emissions. Two primary options for regulating these emissions include covering them under a broad pricing program or mandating a particular control technology or performance standard. Each is discussed below.

Include industrial N_2O and process CO_2 emissions in an economywide cap-and-trade (or tax) program

Including nitrous oxide and process-CO_2 emissions from industrial sources in a cap-and-trade program should be straightforward given the relative ease of measuring emissions "at the smokestack." This approach would allow producers to weigh the relative costs of emissions allowances against the costs of installing and operating new control technology or improving process efficiency to reduce emissions. The price signal generated by inclusion in a cap-and-trade system would also provide incentives for research into improved control devices—such as catalysts for N_2O—and alternative production processes that are less emissions-intensive.[22] Many of these stationary-source emissions are covered in current GHG regulatory proposals. For example, almost all legislative proposals to date have covered the electric power sector (which includes stationary combustion sources of N_2O) and most economywide approaches include emissions from nitric and adipic acid production.

Use control technology mandates or efficiency and performance standards

In the case of many stationary sources—nitric and adipic acid production, for example—known technologies exist for controlling GHG emissions. Thus another regulatory option for these sources would be to simply mandate the use of certain control technologies. However, this approach would likely involve large capital expenses for some industries—for example, almost all nitric acid plants built since the late 1970s have been designed to operate with selective catalytic-reduction units because of lower operating costs and these plants would be forced to redesign their processes to operate with new emissions controls. Further, a technology mandate would not provide the same incentives for research and development to continue improving emissions performance. Some firms have called for performance or efficiency standards to be used to control process-CO_2 emissions rather than including these emissions in a cap-and-trade program, arguing this approach would provide a greater level of cost

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[18] U.S. EPA, 2007. Chapter 4, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, EPA 430-R-07-002, EPA: Washington, DC.

[19] The overwhelming source of U.S. anthropogenic N_2O emissions—more than three-fourths of the total—is agricultural soil management. The stationary sources discussed here account for about 8 percent of U.S. N_2O emissions.

[20] U.S. Climate Change Technology Program, 2005. Technology Options for the Near and Long Term, Section 4.4.1. Available at http://www.climatetechnology.gov/library/2005/tech-options/index.htm Accessed August 21, 2007.

[21] U.S. EPA, 2007. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, Section 4.16, EPA 430-R-07-002, EPA: Washington, DC.

[22] For example, one technology under development is a cokeless iron-making process. U.S. Climate Change Technology Program, 2005. Technology Options for the Near and Long Term, Section 1.4.3. Available at http://www.climatetechnology.gov/library/2005/tech-options/index.htm Accessed August 30, 2007.

certainty for affected firms.[23] While an appropriately designed efficiency or emissions performance standard might be more flexible and efficient than mandating the use of particular control technologies, it remains less efficient than inclusion in a broader market-based policy and still has drawbacks in terms of creating incentives for continuous improvement.

Methane emissions from coal mines

Methane (CH_4) emissions from coal mines account for about 0.8 percent of U.S. GHG emissions. As coal is mined, methane trapped in coal seams or in surrounding strata is released. The majority of coal-mine methane emissions (over 60 percent) comes from underground mines, where greater geologic pressure creates and traps larger volumes of this gas. Methane emissions from surface mines are much smaller; they cannot be captured and escape as fugitive emissions into the atmosphere. Small amounts of fugitive emissions are also released from abandoned mines and during post-mining activities including coal processing, storage, and transport.

Methane in underground mines poses a hazard to mine workers, and so has to be extracted or ventilated for safety reasons. Methane is typically liberated from underground coal seams in one of three ways: pre-mine drainage wells, gob wells, or mine-ventilation air systems.[24] Pre-mine drainage wells are drilled months or years prior to mining and extract a highly-concentrated gas (typically over 95 percent methane) that can be sold for commercial distribution to natural gas pipelines or used onsite for heat or power. Most methane from pre-mine drainage wells is thus not emitted to atmosphere. Gob wells exhaust methane released in the fractured rubble zone, called the "gob" area, that forms as the coal seam is mined and the surrounding strata collapse. Because methane concentrations in the gob area are still relatively high (30–90 percent), it is sometimes used onsite or enriched for sale to pipelines, but is also frequently vented to the atmosphere. Finally, mine-ventilation air systems ensure that methane concentrations in the mine are at safe levels. The concentration of methane in ventilated air is too low—below 1 percent—to allow for economic recovery and use in most cases. Therefore, the gas is usually vented.[25] Options for taking advantage of GHG-abatement opportunities associated with coal-mine methane emissions include directly including these emissions, where possible, under a broader cap-and-trade program; covering these emissions through an offsets program; and a combination of both. Each is discussed below.

Include coal-mine methane in an economywide cap-and-trade (or tax) program

Some proposals have called for coal-mine methane emissions to be directly included in a broader GHG cap-and-trade program. This would be relatively straightforward for emissions from underground mines, as these are captured by active degasification or ventilation systems that can be monitored with relative ease.[26] Inclusion in a broader pricing policy would create incentives for mine owners to recover and use captured methane, reinforcing an existing trend that has seen the amount of methane recovered and used by mines more than double since 1990 (as a result, total methane emissions from underground mines have declined over the last two decades).[27] This approach would be hard to apply, however, to the remaining 40 percent of coal-mine methane emissions from surface mines, abandoned mines, and post-mining activities, where monitoring emissions is far more difficult.

Include coal mine methane in an offset program

Given the difficulties of regulating coal-mine methane directly, it may be easier to include these emissions in a broader policy *indirectly*, via an offsets program. Mine operators (or other project developers) could conduct activities to reduce emissions that would let them earn emissions credits on a project basis. These activities would be voluntary and would occur in response to the financial incentives generated by the allowance market (under a cap-and-trade system) or by the potential for tax rebates (under an emissions tax system).

Adopt a hybrid approach

A third alternative is to adopt a hybrid approach, in which emissions from underground mines are directly included in the cap (meaning that mine owners would need to submit allowances for these emissions), while emissions from surface or abandoned mines, or from fugitive sources, would be addressed through an offsets program. Although technically feasible, adopting different modes of regulation for portions of the mining industry seems likely to be politically contentious.

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[23] For example, the cement industry in California is urging regulators to employ "Japan-style" energy efficiency requirements rather than including cement producers in a state-wide cap-and-trade program created to implement Assembly Bill 32. G. Hyatt, 2007. "Cement Makers Back Energy Efficient Rule Over Carbon Cap-And-Trade", *Carbon Control News*, Vol. 1, No. 25, July 2, 2007.

[24] Further information on methane from underground coal mines can be obtained from the U.S. EPA Coalbed Methane Outreach Program (http://www.epa.gov/cmop/index.html). Specific information on the types of wells used to extract methane came from U.S. EPA, 2005. *Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Profiles of Selected Gassy Underground Coal Mines 1999-2003* EPA 430-K-04-003. EPA: Washington, DC.

[25] U.S. Climate Change Technology Program, 2005. *Technology Options for the Near and Long Term*, Section 4.1.4. Available at http://www.climatetechnology.gov/library/2005/tech-options/index.htm Accessed August 21, 2007.

[26] In some cases emissions are already monitored; for example, the Mine Safety and Health Administration maintains a database of methane emissions from ventilation air.

[27] U.S. EPA, 2007. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2005*, Section 4.16, EPA 430-R-07-002, EPA: Washington, DC.

ISSUE BRIEF 15

OFFSETS: INCENTIVIZING REDUCTIONS WHILE MANAGING UNCERTAINTY AND ENSURING INTEGRITY

DANIEL S. HALL

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Daniel S. Hall

Summary

Most market-based regulatory proposals to limit greenhouse gas (GHG) emissions include provisions that allow market participants to seek reductions outside the regulated system. These reductions are typically referred to as offsets. Offsets are attractive because they can expand the available pool of low-cost reduction options, particularly in the near future. Many potential offset projects, however, present challenges because the emissions reductions they generate are difficult to measure or carry risks of impermanence. How can an offset program be designed to incentivize reductions while also ensuring their integrity?

- This memo briefly describes what offsets are, which sectors they are in, and how they have been used in other regulatory programs. We then discuss policy design features and options for addressing risks and uncertainties associated with low-quality offsets. In broad terms, the results of this exploration suggest that an offset program can be used to generate incentives for reductions that would be difficult to motivate or mandate in other ways, but creative approaches will be needed to manage offsets with uncertain environmental benefits.

- Offsets should be real, additional (beyond what would have happened anyway), permanent, and verifiable. These are the commonly accepted criteria for determining the quality and eligibility of offset projects.

- Offsets can be used to achieve emissions reductions in some sectors and for some activities that are difficult to regulate directly. Examples include biological sequestration of carbon; destruction of fugitive methane emissions from sources such as landfills or coal mines; or changes in agricultural soil management practices to reduce nitrous oxide emissions. Offsets can also enhance the dissemination of advanced technologies for reducing carbon dioxide (CO_2) emissions, particularly in developing countries.

- There is a fundamental tension between generating a large supply of low-cost offsets and ensuring they are high quality. Broadly speaking, two approaches can be used to mitigate—but not eliminate—this tension. The first is to simplify registration and crediting procedures for offset projects that generate emissions reductions which can be verified with a high degree of confidence. The second, complementary approach is to design offset programs that limit the consequences of potentially over-crediting projects in cases where the environmental benefits are less certain. Policymakers will have to decide how to balance trade-offs between minimizing transaction costs and ensuring the environmental integrity of offsets.

- Mechanisms that can minimize the administrative complexity and cost of offset programs include two-step registration procedures that determine project eligibility before developers commence projects, positive lists of pre-approved

offset project types, and tiered systems that use defined crediting levels for different types of projects.

- Policies to address projects with uncertain environmental benefits include credit limits and set-asides that specify a maximum aggregate level of offsetting reductions that can be used for compliance. These effectively place an upper bound on the risk from uncertain or difficult-to-verify projects. Non-uniform crediting can be used to discount certain project types, presumably on a risk basis. Rental credits can be used to limit exposure to offsets from projects that may not produce permanent emissions reductions.
- Policy choices for offset programs must be evaluated holistically. In designing such programs, policymakers should decide first what the overarching goal of the offset program is: generating the maximum number of offsets, minimizing transaction costs for project developers, ensuring environmental benefits, or some combination of these objectives. Designing an offset program will entail making choices about which suite of policy tools will function together to accomplish the goal.

What Are Offsets?

Offsets do what their name implies: they allow emissions reductions outside of a regulated system to 'off-set' emissions-reduction requirements inside the system.[1] The use of offsetting reductions is not required by law; rather, regulations set rules for which emissions-reduction activities can qualify as offsets. Private agents are motivated to pursue these offsets by their value as an alternative compliance option within the regulated system. Under a cap-and-trade program with offsets, for example, regulated entities could have four compliance options: (1) reducing emissions, (2) buying emissions allowances, (3) purchasing offset credits from unregulated entities that have reduced emissions, or (4) undertaking emissions-reduction projects that qualify as offsets within unregulated portions of their own operations.[2]

Although most commonly associated with cap-and-trade proposals, offsets can also be used under a mandatory emission tax as a way to offset the tax. Offset credits would reduce the tax liability of sources (as well as tax revenues to the government).

> Offsets come with a fundamental tension: how can the quality of offsets be assured at a low cost?

Offsets can be a valuable addition to regulatory programs because they expand the available pool of emissions reductions, presumably to include more low-cost options in sectors of the economy that are not regulated or across a wider geographical area. In other words, incorporating offsets can reduce the cost of meeting a given emissions target, make a more stringent target achievable at the same cost, or some combination of both (that is, reduce costs *and* allow for a more stringent target). By increasing the supply of available allowances, offsets can also increase the liquidity and flexibility of allowance markets, and reduce price volatility.

Offsets come with a fundamental tension, however: How can the quality of offsets be assured at a low cost? Performance criteria commonly applied to offsets require that emissions reductions are real, additional, and permanent. That is, offsets should be credited only to activities that actually reduce emissions, are additional to what would have happened anyway,[3] and do not merely shift emissions to another time or place. Ensuring that this is the case requires measurement, monitoring, and verification procedures. Ideally, such procedures would verify high-quality offsets while remaining transparent, streamlined, and administratively simple. In reality, there are trade-offs between ensuring environmental integrity and minimizing transaction costs.

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[1] In addition to regulatory offsets, there are voluntary or "retail" offsets. These are typically marketed to individual consumers and public awareness of their existence has been increasing. (Witness the New Oxford American Dictionary's selection of the term "Carbon Neutral" as the 2006 Word of the Year.) The voluntary market has grown significantly in the last three years, but remains a small part of the overall market. According to a World Bank report on the carbon market (K. Capoor and P. Ambrosi, 2007. *State and Trends of the Carbon Market 2007*, World Bank: Washington, DC.), compliance offsets—those used to meet regulatory requirements—accounted for more than 98 percent of the transactions in offset markets in both 2005 and 2006. This paper focuses on compliance offsets.

[2] This last option would be particularly pertinent for multinational companies whose operations were regulated in some countries but not in others.

[3] Additionality can be a challenging concept to define and establish, particularly since it is hard to know what would have happened in a "business-as-usual" world where there was not an incentive to generate offsets. The Clean Development Mechanism (CDM) of the Kyoto Protocol, an offset program discussed at length in the text box in this issue brief, has established a methodology for demonstrating additionality. It requires projects to show that some barrier to emissions reductions exists, that the project would not occur without CDM investment, and that the activity is not already a common practice. Source: CDM – Executive Board, "Combined tool to identify the baseline scenario and demonstrate additionality" Version 02.1. Available at http://cdm.unfccc.int/methodologies/Tools/EB28_repan14_Combined_tool_rev_2.1.pdf Accessed September 10, 2007.

Where Will Offsets Come From?

This section explores potential types of offset projects. What are some key sectors for offsets? What types of offset projects might be undertaken? What implementation challenges might they face? What regulatory concerns do they raise?

Offset opportunities are frequently concentrated in sectors or among activities that may be difficult to regulate directly, such as reducing fugitive emissions or lowering emissions associated with land-use practices. In some cases these emissions cannot be easily or reliably measured—as with soil carbon emissions (or sequestration)—and so are not good candidates for inclusion in a mandatory regulatory system such as a cap-and-trade program or carbon tax. In other cases, it may be difficult to determine, and hence regulate, emissions ex ante, but once an offset project is performed—for example, the capture and destruction of methane from landfills—determining the emissions reduction is straightforward.

One distinction among offsets projects is whether they are domestic or international in nature. To avoid double counting, domestic offsets would be limited to activities that are not already included in a mandatory program. For example, eligible domestic offset projects might address small-source emissions (if these are unregulated), biological sequestration, agricultural emissions, or other fugitive emissions; they typically would not include emissions at large point sources likely to fall under a mandatory program.[4] International offsets in countries without binding emissions caps, on the other hand, could involve a much wider range of projects including, in addition to the types of domestic offset projects noted above, projects that reduce energy- or industrial-sector emissions in developing countries through the transfer of advanced technologies. International offsets may face additional implementation and financing hurdles, however, depending on the strength of market institutions and legal frameworks in host countries.

Some of the projects and activities commonly considered for inclusion in a domestic offsets program are briefly reviewed below. The list is not intended to be exhaustive—rather it is based on projects that have been recognized so far under the Clean Development Mechanism (CDM) of the Kyoto Protocol and on the general disposition of U.S. GHG emissions, particularly fugitive emissions.[5] For each category of emissions, we discuss a few representative project types and identify potential problems in demonstrating that reductions are real, additional, and/or permanent. The information is also summarized in Table 1.

Biological Sequestration of Carbon

Biological sequestration projects focus on two distinct types of carbon reservoirs: forests and soils. Both contain large quantities of carbon with annual fluxes—changes in stored carbon—that significantly influence net CO_2 emissions to the atmosphere. Forestation projects involve either protecting existing forest that is threatened, or creating and sustaining new forests. These projects can raise significant permanence concerns; namely, how long will a stand of trees be preserved? Leakage problems can also be problematic, since protecting one stand of trees may just lead to another stand elsewhere being exploited. Soil carbon sequestration involves changing land-use or land-management practices (for example, in agriculture) such that additional carbon is sequestered in the soil. Net sequestration from soil carbon projects is often difficult to measure and these projects also raise concerns about permanence.

Non-CO_2 Agricultural Emissions

A few key activities generate most fugitive non-CO_2 GHG emissions in the agriculture sector (further discussion of sources and emission-reduction opportunities in this sector can be found in Issue Brief #13). The first category of activities involves methane (CH_4) emissions, primarily from large concentrations of animal waste (for example, manure) and ruminant animals, such as cows, whose digestive processes produce methane. Potential offset projects to address this category of emissions include capturing the methane from animal waste and either flaring it or using it to generate power or heat; options for reducing digestive emissions from ruminant animals are more limited but could involve changes in feed and grazing practices or the use of nutritional supplements. A second important category of agricultural emissions involves the release of nitrous oxide (N_2O) from soils. Nitrous oxide emissions can be reduced using soil management practices such as changing the application method and amount of fertilizer used, the types of crops grown, and irrigation practices. Quantifying these emissions and documenting reductions, however, is difficult.

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[4] Eligibility could also be influenced by other regulations; for example, an offset program might generally allow soil sequestration projects to receive offset credits, but exclude sequestration projects on land enrolled in the Conservation Reserve Program. Since these areas are already being compensated for environmental benefits associated GHG reductions might not be considered sufficiently "additional."

[5] For more information on U.S. GHG emissions see Issue Brief #1.

Other Fugitive Emissions

Fugitive emissions are not released from a concentrated source, like a smokestack or tailpipe, but often involve leaks or evaporative processes. Potential offset projects include capturing fugitive methane emissions from landfills or coal mines, detecting and repairing leaks in natural gas pipelines, and reducing emissions of sulfur hexafluoride (SF_6) from electrical transformers.[6] In some cases it can be difficult to demonstrate that emissions reductions are in addition to the reductions that would have happened anyway, since there are private incentives to reduce many types of fugitive emissions.

Energy Systems

Domestic energy systems would likely be included in any domestic regulation,[7] but energy-system offsets could still be created through projects in other countries that lack binding emissions constraints. Examples include renewable energy projects, such as installing wind or hydroelectric generators, in other countries; generating power using methane emissions from waste treatment facilities overseas, thus both eliminating methane emissions and displacing some power generation; and energy-efficiency or fuel-switching projects that reduce CO_2 emissions outside the United States. Verifying benefits from these types of projects is usually relatively straightforward, although in some cases additionality could be a concern.

Industrial Gases

Although domestic industrial emissions, including emissions of non-CO_2 gases, would likely be included in any domestic regulation, offsets could be created by reducing emissions from industrial sources overseas. These types of offset projects have represented the majority of CDM projects undertaken so far. Examples include destroying hydrofluorocarbon (HFC) emissions associated with refrigerant production, reducing nitrous oxide emissions from the production of adipic or nitric acid, or reducing non-energy CO_2 emissions from industrial processes such as cement manufacture. These projects have proved popular under the CDM because there are abundant opportunities for low-cost reductions. Concern is growing, however, that some of these projects may be creating perverse incentives to continue or even expand activities that create other environmental problems.

Table 1 Overview of Offset Project Categories

Category	Representative Projects	Concerns
Biosequestration	Forest/soil sequestration	Additionality, permanence, MM&V*
Agricultural projects	Manure methane capture, soil management practices (N_2O)	MM&V
Fugitive gases	Landfill methane, coal-mine methane	Additionality
Energy systems (international)	Renewable energy, energy efficiency, fuel switching	Additionality
Industrial gases (international)	HFC-23, N_2O, industrial CO_2	Perverse incentives? (See discussion of CDM at end.)

*MM&V: measurement, monitoring, and verification

Primary Challenges in Designing an Offset Program

This section explores the design features and options that policymakers should consider when creating offset programs. Two sets of issues must be decided. The first concerns the broad design of the offset system, including defining the overall universe of potential projects. Ideally the approach used to determine eligibility for offset projects would minimize administrative complexity and uncertainty for offset developers. The second set of issues involves striking a balance between encouraging as much inexpensive, offset-based emissions mitigation as possible and protecting the integrity of the overall regulatory program in terms of its ability to meet defined environmental objectives. This challenge, not unrelated to the first, largely comes down to deciding how to deal with lower quality offsets.

Options for Determining Project Eligibility

Rather than deciding project eligibility on a case-by-case basis, which can be time consuming and impose high transaction costs, alternative mechanisms can facilitate quicker and cheaper review and measurement of offsets.

Positive list

A "positive list" identifies activities that are eligible to create

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[6] Fugitive emissions of synthetic gases, like SF_6, could potentially be regulated directly under a mandatory domestic GHG program, either by including industrial gas production sources in the cap (or tax), or by using a deposit-refund system in which permits are required for producing a gas and credited back when the gas is destroyed. See Issue Brief #14 on non-CO_2 gases for further disucssion of regulatory options for industrial gases.

[7] Domestic energy systems would not qualify for offsets when covered by mandatory regulation because projects that reduced emissions (for example, energy efficiency projects) would reduce regulatory obligations in the program (whether the obligation is to submit allowances under a cap-and-trade program or to pay a tax on GHG emissions). In other words, the regulation itself would create direct incentives for reductions at covered sources. Under some mandatory programs—upstream cap-and-trade or carbon taxes on fossil-fuel production, for example—provisions would be needed to credit activities that trap and sequester post-combustion emissions, such as carbon capture and storage (CCS) projects. However, these provisions should be thought of as a refund (of allowances or taxes) rather than an offset. They are analogous to the emitter never bearing any regulatory obligation in the first place (as would likely be the case for an emitter that employed CCS under a downstream cap-and-trade program or carbon tax).

offsets; it can also define a fixed crediting level for these activities. This approach has been adopted in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program for limiting electric-sector GHG emissions being developed by several northeastern U.S. states. A positive list can ease administrative burdens and reduce uncertainty for project managers, particularly when dealing with common and well-understood project types.

Two-step process

For projects that require individual review, a two-step process may be appropriate in which offset developers submit a proposal and receive a determination of eligibility prior to beginning work. The second step occurs upon project completion when offsets are verified and credits issued. The CDM currently uses a two-step process—however, the fact that the first step can take a year or longer may discourage participation and investment in offset projects under this program.[8]

Tiered offset systems

Tiered systems are similar to positive lists in that they create standard eligibility and crediting rules. Various offset activities are grouped in specific tiers. "Top-tier" projects—those that are well-understood and easily verified—would have the simplest approval, verification, and crediting procedures. Tiered systems can increase the transparency of the offset approval process.

International offsets

While almost all proposals for offset programs allow domestic offsets, they may also incorporate international offsets. International offsets can expand the pool of available projects, but they may be more difficult to evaluate and administer. They may also enjoy less political support, as there would likely be greater political enthusiasm for generating reductions at home rather than abroad.

Offsets from other programs

As other national and international institutions create offset programs, there is the possibility that the United States could make these offsets fungible with its own. For example, certified emissions reductions (CERs) generated under the CDM program could be eligible for use as a domestic compliance option within a U.S.-based program, as has been proposed for RGGI.

Options for Dealing with Low-quality Offsets

Some types of offsets are well understood and easy to measure and verify. For example, measuring the capture and destruction of landfill methane or industrial gases is relatively straightforward. Inevitably, however, offset programs will have to handle activities that present measurement and verification challenges. There may be uncertainties in quantifying reductions (e.g., for soil carbon sequestration). There may be concerns about permanence or leakage (e.g., in the case of reforestation projects). It may be difficult to demonstrate additionality for some types of projects (e.g., showing that a project to capture methane for use or sale would not happen absent offset credits).

The challenge for an offset program is to balance the need to achieve real reductions against the desire to encourage widespread use of cost-effective mitigation options among otherwise unreachable sectors or activities. If the latter were not an objective, an offset program could simply apply strict eligibility rules—high standards for verifying additionality, permanence, and lack of leakage would ensure that (virtually) all offsetting reductions were real.[9] This approach would ensure high-quality offsets, but has disadvantages: large administrative costs and substantial burdens for offset-project developers could discourage investment. If an offset program is going to produce a reasonable supply of high-quality, low-cost reductions from unregulated sources it will need to incorporate creative and suitable approaches to crediting projects with uncertain environmental value.

Set-asides

An option that may be attractive for incentivizing particularly "high-risk" projects in the context of an emissions trading program is to carve out a portion of allowances under the overall cap and set it aside for these activities. For example, one Congressional proposal calls for 5 percent of the total allowance pool to be set aside for agricultural soil sequestration projects.[10] Set-asides can incentivize particular projects while guaranteeing the integrity of the cap in a cap-and-trade system. If five percent of allowances are credited to agricultural sequestration activities under a set-aside, capped and uncapped emissions will be five percent lower than they would otherwise be if these activities generate real reductions. If they do not generate real reductions, total emissions will still stay within the cap.

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[8] Natsource LLC, 2007. *Realizing the Benefits of Greenhouse Gas Offsets: Design Options to Stimulate Project Development and Ensure Environmental Integrity,* National Commission on Energy Policy: Washington, DC.

[9] The CDM has essentially taken this approach. Despite high administrative costs, the program looks poised to produce a substantial volume of offsets over the compliance period of the Kyoto Protocol. (See further discssion in CDM text box.)

[10] Bingaman-Specter "Low Carbon Economy Act of 2007", S. 1766, 110th Congress, section 201(a)(1) and section 205.

Credit limits

Another regulatory option for handling low-quality offsets is to limit the absolute number of credits available for certain types of activities. For example, another Congressional proposal limits the use of offset credits to a maximum of 30 percent of a covered entity's total compliance obligation.[11] The difference between this approach and a set-aside is that crediting projects that do not produce real emissions reductions will result in total emissions above the cap level. Essentially identical results can be achieved, however, by adjusting the cap level to account for this possibility. To illustrate this, consider two hypothetical cap-and-trade proposals. The first establishes a cap level of 100 tons and a set-aside of 10 allowances from the 100 allowances available under the cap (each allowance represents 1 ton of emissions). The second program establishes a cap level of 90 tons and limits offset credits to 10 tons. Assuming the same types of projects are eligible under both proposals, thus introducing exactly the same risks (of permanence, leakage, etc.), and assuming the set-aside and offset limits are exhausted in each case, the two proposals have identical consequences. If emissions reductions from credited projects are real and permanent, overall emissions will total 90 tons under both proposals. If, on the other hand, credits are claimed for projects that turn out to have no real environmental benefit, actual emissions will total 100 tons in both cases.[12] The lesson for policymakers is that the choice of which approach to use is less important than the size of the set-aside or credit limit in the context of the overall cap and the rules used to verify quality (with all the same trade-offs noted above).

Credit limits (and set-asides) do raise a critical issue, however, in terms of their potential to distort investment incentives for offset projects. With either limits or set-asides, the question arises: how will offset credits be distributed when there are more applicants than available credits? Credits could be awarded on a first come, first serve basis or prorated to individual projects such that the total awarded does not exceed the limit or set-aside amount (in that case, project developers would be credited for something less than the emissions reductions they achieve). In either case, uncertainty about how—or whether—their project will be credited could discourage developers from investing in offset activities.

Non-uniform crediting

While credit limits and set-asides are essentially quantity-based instruments for handling risky offset projects, non-uniform crediting is analogous to a price-based approach. The idea is that offset projects receive either more or less than one-to-one crediting: uncertain or risky offset projects receive offset credits at a discounted rate, while other projects receive full or even extra credits. For example, soil carbon sequestration projects might receive credits worth 80 percent of the current best estimate of sequestration.[13] The proposed Lieberman-McCain legislation uses discounted crediting for sequestration projects based on the uncertainty in estimating net emissions benefits: if the range of estimates for a class of projects is broad, the offsets awarded for such projects are near the bottom (low) end of the range.[14] A discounting approach helps address areas where benefits are likely but uncertainties (in measurement, permanence, etc.) remain large. By allowing projects that involve nascent or difficult emissions-reduction opportunities to receive some credit, this approach could promote some near-term investment in developing new abatement options while holding out hope that increased experience and improvements in measurement capabilities would allow crediting levels to be adjusted closer to projects' true value at some point in the future.

As noted previously, non-uniform crediting can also allow greater than one-to-one crediting. If there are certain offset activities that regulators particularly wish to encourage or reward, then awarding additional credit (beyond the best estimate of actual project reductions) will provide even stronger incentives. The Bingaman-Specter legislation uses this approach to encourage investment in carbon capture and sequestration (CCS): eligible geologic sequestration projects receive allowances at a greater than one-to-one rate from 2012 to 2029 (starting at 3.5 times the amount sequestered from 2012 to 2017).[15] Policymakers must recognize, however, that bonus credits represent an additional subsidy and will thus encourage a level of investment in eligible activities that is likely to be inefficient unless it can be justified on some other (non-climate) grounds.

Rental credit

Offset projects characterized by high risks of impermanence (for example, biological sequestration) could also be dealt with through credits that are "rented" rather than transacted once and for all. The Lieberman-McCain proposal uses a version of this approach: any sequestration projects that are

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[11] Lieberman-McCain "Climate Stewardship and Innovation Act of 2007", S. 280, 110th Congress, section 144(a).

[12] If no offset activities are performed and hence no offset credits are claimed, emissions will total 90 tons.

[13] This is effectively the approach used for soil sequestration projects within the offset program of the Chicago Climate Exchange (CCX). (The CCX is a North American-based GHG emission trading system that companies can join voluntarily by committing to reduce their emissions. The CCX manages its own offset program.) Each year 20 percent of CCX-eligible offsets that are generated through soil sequestration are placed into a reserve pool to hedge against future reversals in carbon storage. Source: Chicago Climate Exchange, "Soil Carbon Management Offsets" Available at http://www.chicagoclimatex.com/docs/offsets/CCX_Soil_Carbon_Offsets.pdf Accessed September 7, 2007.

[14] "Climate Stewardship and Innovation Act of 2007", S. 280, 110th Congress, section 144(c)(3)(B).

[15] Bingaman-Specter "Low Carbon Economy Act of 2007", S. 1766, 110th Congress, section 207(a)(3).

submitted for credit must be reevaluated every five years and if the net benefits claimed previously have declined (for example, a forest fire destroys a strand of trees that had been claimed), then covered entities must submit new allowances or credits to cover the shortfall.[16] An important political question in designing a credit rental proposal is deciding which party will be liable if previously rented offsets disappear or diminish in value: the covered entity that surrendered the offset credit to meet its compliance obligation or the unregulated entity that generated the offset in the first place. In either case, the idea of rental credits is attractive from an economic perspective because—assuming offset providers and buyers have good information about the likely permanence of emissions reductions from particular projects—they could account for these risks in managing their use of offsets. Problems could arise, however, if private actors expect the government to be the insurer of last resort: for example, if there were an expectation that in the wake of a forest fire which wiped out a large number of offsets the government would merely forgive resulting emissions. Such expectations would encourage overinvestment in high-risk projects, which could then have the perverse effect of increasing political pressure on the government to be the insurer of last resort in the case of a catastrophic event.

Conclusion

The design options discussed above reflect lessons learned from early offset programs, particularly the CDM. Many of these design option can be used in conjunction with each other. Indeed, policymakers must make decisions about most of the issues reviewed here, even if only implicitly. Finally, it is helpful to evaluate the various choices and options as a package, and to consider the overall implications of a given set of design choices.

For example, policymakers may choose to create an offset program that is outside the cap, consists only of domestic offsets, uses a tiered system with a positive list to determine project eligibility and crediting levels, and utilizes risk-based discounting to credit different project tiers. Such a program would be set up to minimize administrative burden. It would hedge environmental risk through a market mechanism, like discounting, rather than through regulation by offset quotas or caps. On the other hand, policymakers may prefer a tiered system that uses either set-asides or credit limits for certain tiers of activities, and utilizes rental credits with strict liability rules for other tiers. Such a system would be set up to maximize environmental integrity by reducing the risk that awarding credit to low-quality offsets results in emissions above the cap. Or, again, policymakers may opt for a very open system that allows unlimited offset credits from all sectors, recognizes international offsets, and uses uniform crediting, even from riskier projects. This system would be designed to minimize the overall costs of compliance, albeit at some risk to the environmental integrity of the program. All these design choices will have a substantial impact on the degree to which offsets can, on the one hand, expand the pool of low-cost mitigation options while on the other hand potentially compromising, or at least introducing uncertainty about, the overall environmental benefit achieved by the regulatory program.

The Clean Development Mechanism

Created under the Kyoto Protocol, the CDM represents the largest offset program in the world.[17] Under the CDM, credits are awarded for specific project activities in developing countries that reduce GHG emissions.[18] Developed countries with binding emissions targets under Kyoto can then purchase these credits to count towards their own compliance. The use of CDM credits to meet domestic regulatory obligations has also been proposed in countries that have not accepted emissions-reduction targets under Kyoto.[19]

The CDM process has stringent requirements. It requires project design documents to be independently evaluated (a process called validation), approved by a host country, and then reviewed and registered by the CDM Executive Board. There are high standards for demonstrating that reductions are additional and permanent. Once a project is registered and activities are underway, all emissions reductions must be measured and verified by an independent party before any offset credits, called Certified Emissions Reductions (CERs), are issued.

Each CER represents one metric ton of reduced carbon dioxide-equivalent (CO_2e) emissions. CERs can be purchased

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[16] "Climate Stewardship and Innovation Act of 2007", S. 280, 110th Congress, section 144(c)(1).

[17] A smaller offset program has also emerged under the Chicago Climate Exchange (CCX), a private North American-based GHG emissions trading system that companies can join voluntarily by committing to reduce their emissions. The CCX manages its own offset program. As of August 2007 the CCX had issued offset credits to 34 projects—25 in the United States, 9 overseas—totaling almost 15 million metric tons CO_2e of reduced emissions. More than half of the emission reductions were from soil carbon sequestration projects. (Chicago Climate Exchange, "CCX Registery Offsets Report, Offsets and Early Actions Credits Issued as of 08/28/2007." Available at http://www.chicagoclimatex.com/offsets/projectReport.jsf Accessed August 28, 2007.) The CCX offset program has been criticized for having insufficient standards for ensuring that reductions—particularly from soil projects—are real and additional. Further, the CCX itself has faced criticisms for being too industry-friendly and lacking public transparency. (Goodall, J., 2006. "Capital Pollution Solution?", *The New York Times Magazine*, June 30, 2006.)

[18] The Kyoto Protocol also created a separate category of offset activities called Joint Implementation projects, which are projects conducted within Annex 1 (developed world) countries. To date there has been much less activity in JI than in CDM.

[19] For example, the Northeast and mid-Atlantic states have proposed to recognize CDM credits under their Regional Greenhouse Gas Initiative (RGGI) for limiting power-sector carbon emissions if the price of RGGI allowances rises above some defined threshold.

by countries to meet Kyoto obligations; they can also be purchased by firms—for example, as a means to comply with the European Union's Emission Trading System (EU ETS) (which in turn is being used by EU countries to help meet their Kyoto obligations).

As of July 2007, more than 700 CDM projects had been registered and another 1,500 applicants had submitted project design documents for validation. Altogether these projects in the CDM pipeline represent cumulative emissions reductions totaling approximately 2.2 billion metric tons CO_2-e through 2012.[20] For comparison, the projected compliance shortfall among Kyoto participants (including the EU, Japan, and New Zealand, but excluding Canada) from 2008 to 2012 is 2.0 billion metric tons CO_2e.[21] To date, few CERs have been issued, as most CDM projects are still relatively recent.

Figures 1 and 2 show the distribution of CERs from various project types, first for the 700 currently registered projects and then for all 2,200 proposed projects, including those now in the CDM pipeline.[22] As is evident from the figures, projects involving non-CO_2 GHG emissions account for the majority of emissions reductions. The single largest share of reductions comes from projects that reduce HFC-23 emissions from HCFC-22 production. These projects accounted for an even larger portion of early CDM entrants, as they represented some of the lowest-cost emissions-reduction options available internationally, but their share has fallen as the opportunities for HFC-23 control have been nearly exhausted.[23] Projects to generate nitrous oxide (N_2O) reductions have mostly involved controlling emissions from adipic acid production. By contrast, methane (CH_4) reduction projects have been implemented in a variety of sectors, including coal mines, oil and natural gas production and processing, and various waste management industries, including landfills, wastewater, and animal wastes.

Projects that focus on energy systems, whether they involve energy efficiency, fuel switching (typically to natural gas), or renewable generation, account for a small but growing

Figure 1 Currently registered CDM projects (July 2007); expected volume of 1,015 million CERs by 2012

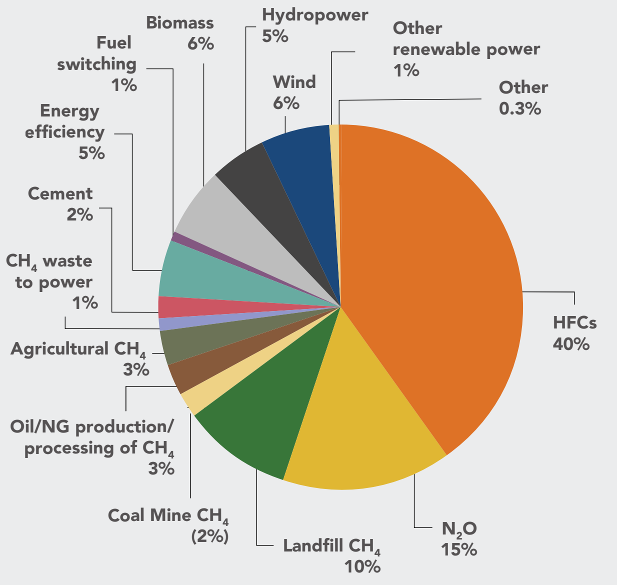
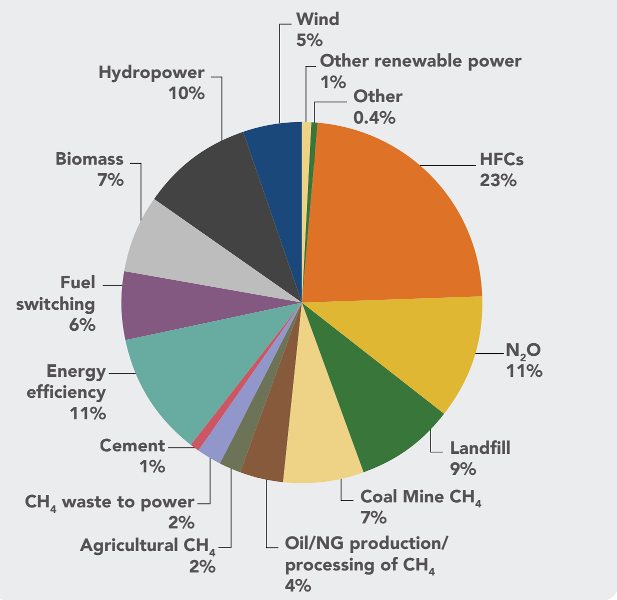


Figure 2 All CDM projects "in the pipeline" (July 2007); expected volume of 2,180 million CERs by 2012



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[20] The actual yield of delivered CERs will almost certainly be less. The World Bank report mentioned previously (Kapoor and Ambrosi 2007. *State and Trends of the Carbon Market 2007,* World Bank: Washington, DC.) estimates a likely CDM yield over the Kyoto compliance period (2008–2012) of 1.5 billion tCO_2e. The current issuance success rate among the few projects that have already been issued CERs is about 85 percent *(UNEP Riseo CDM/JI Pipeline Analysis and Database, July 2007),* which extrapolates to a little less than 1.9 billion tCO_2e.

[21] Kapoor and Ambrosi 2007. *State and Trends of the Carbon Market 2007,* World Bank: Washington, DC. Canada is projected to have a large Kyoto compliance shortfall (perhaps 1.3 billion tCO_2e). Whether this will translate to increased demand for CDM credits is uncertain, however, because the Canadian government has published a report stating that the country will fail to meet its emissions reduction target under the Protocol. (Point Carbon, "Canadian government submits Kyoto compliance plan, without compliance", *Carbon Market North America,* August 29, 2007.)

[22] *UNEP Riseo CDM/JI Pipeline Analysis and Database,* July 2007. Available at http://cdmpipeline.org/ Accessed August 2, 2007.

[23] Wara, Michael, 2006. *Measuring the Clean Development Mechanism's Performance and Potential,* Program on Energy and Sustainable Development Working Paper #56, Stanford: Palo Alto, CA, and Wara, M., 2007. "Is the global carbon market working?", *Nature*, 445 (7128): 595-596. Compare the pipeline analyses from these papers (April 2006 and January 2007) with the July 2007 analysis in this paper and with the calculations of the total potential volume of HFC-23 reductions in Wara 2006.

portion of CDM reductions. They represent less than one-quarter of reductions from the 700 currently registered projects but are the fastest-growing category of activity for CDM projects. If all projects in the CDM pipeline are credited with currently projected reductions, energy projects in developing countries will account for more than 40 percent of all CERs generated by 2012.

Prices for CERs are driven by demand, particularly from Europe and the EU ETS, and so are linked to the price of allowances in the EU ETS. Prices in July 2007 for CERs delivered during the Kyoto compliance period (2008–2012) were \$12–\$18 per metric ton CO_2-e when purchase agreements were arranged directly between buyers and project developers. Prices for credits purchased in a secondary market have tended to be around 70 percent of the EU allowance price; thus CERs in the secondary market were selling for about \$20 per metric ton CO_2e in July 2007.[24]

Criticism of the CDM

The CDM process has drawn criticism for having an administratively complex and time-consuming approval and verification process.[25] Multiple approvals must be obtained and even after registration the quantity of credits to be generated is not certain until reductions are verified. The program's stringent eligibility standards are designed to ensure the integrity of emissions-reduction projects but they have the disadvantage of increasing transaction costs for project developers and reducing the universe of projects that can be profitably undertaken.

The CDM program includes some features designed to mitigate these burdens. For example, there is a list of acceptable methodologies with published guidelines for quantifying emissions for common types of projects, which can help reduce the length of the approval process for many applicants. Further, the existence of the registration process allows project developers to confirm that credits will be generated prior to undertaking projects (even if the exact quantity remains uncertain). Despite these features, however, bureaucratic delays and bottlenecks in the project review and emissions verification steps have led to a growing lag between project application and registration, and then between registration and the issuance of credits.[26]

The CDM program has also drawn criticism on grounds that payments for some projects that target certain non-CO_2 gases, particularly HFCs, essentially function as subsidies and thus create incentives to sustain—or even expand—activities that exacerbate other environmental problems. There is particular concern that the program creates perverse incentives for firms in developing countries to continue producing HCFC-22, an ozone depleting substance, so that they can receive CDM credits for destroying HFC-23, a by-product of the HCFC-22 production process.[27] Accordingly, some argue that non-CO_2 gases would be better dealt with by side agreements than in conjunction with CO_2.[28] Critics of the CDM further argue that many of the projects being credited, or those likely to be credited, under the program—particularly where they involve industrial gases like HFCs—are neither promoting technology transfer to less developed countries nor supporting sustainable development for the poor[29]—one of the primary goals of the CDM program as originally conceived under the Kyoto Protocol.[30] Others counter that the value of a multi-gas strategy is that it finds the lowest-cost reductions, wherever they occur, and that an offset market at least ensures that reductions in certain industrial-gas emissions are taking place. One potential strategy for addressing concerns about these gases would be to adjust the crediting rate for projects so that the incentive to reduce emissions is balanced against the perverse incentive to expand opportunities for reducing emissions in the future.[31] In addition, a credible long-term decision about which new emission sources will (or will not) be eligible for offsets would help to eliminate incentives for strategically expanding production.

The CDM is significant for creating the first large-scale market for offset credits in the context of greenhouse gas regulation. It has demonstrated that a market-based system of offset credits can be used to link international emissions reductions, particularly in developing countries, to compliance obligations under a domestic or regional cap. The criticisms that have been leveled at certain aspects of the CDM may offer lessons for policymakers and regulators as countries consider setting up their own offset programs.

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[24] PointCarbon, 2007. "CDM market comment", *CDM & JI Monitor*, July 11, 2007.

[25] *Natsource LLC, 2007. Realizing the Benefits of Greenhouse Gas Offsets: Design Options to Stimulate Project Development and Ensure Environmental Integrity,* National Commission on Energy Policy: Washington, DC.

[26] PointCarbon, 2007. "Bureaucratic delays, lack of auditors clog up CDM process", *CDM/JI Monitor,* August 22, 2007.

[27] The concern arises because, given current prices for CDM credits and low abatement costs for HFC-23, the profits from destroying HFC-23 byproduct and selling the CDM credits are greater than the value of the HCFC-22 production itself. Similar concerns have been raised regarding the relative costs of N_2O destruction from adipic acid production. (Wara, Michael, 2006. *Measuring the Clean Development Mechanism's Performance and Potential,* Program on Energy and Sustainable Development Working Paper #56, Stanford: Palo Alto, CA.) HCFC-22 is used both as a chemical feedstock for synthetic polymers—a process which sequesters the gas without emissions—and in a variety of end-use applications, including as a refrigerant, that result in fugitive emissions. The production of HCFC-22 for non-feedstock purposes is already being phased out by developed countries under the Montreal Protocol, but production in developing countries is allowed to continue without restriction until 2016, at which point a production freeze will go into effect until 2040. After 2040, all production of HCFC-22 worldwide is supposed to cease under the Montreal Protocol (Bradsher, K., 2007. "Push to Fix Ozone Layer and Slow Global Warming", New York Times, March 15, 2007.)

[28] Wara 2007. "Is the global carbon market working?", *Nature*, 445 (7128): 595-596.

[29] Bradsher, K., 2006. "Outsize Profits, and Questions, In Effort to Cut Warming Gases", *New York Times*, December 21, 2006.

[30] Article 12 of the Kyoto Protocol.

[31] For more information see the discussion on non-uniform crediting in the section of the main text that discusses design challenges for offset programs