New Uses of Old Tools: An Assessment of Current and Potential Agricultural Greenhouse Gas Mitigation with Sector-based Policies

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1. Introduction

Since cap-and-trade legislative proposals stalled in the U.S. Senate in 2010, the discussion of policies to increase greenhouse gas (GHG) mitigation has focused more narrowly on expanding policies in the energy sector, which is the dominant source of GHG emissions. Energy policies can provide incentives for expanded bioenergy, from feedstocks supplied by the agriculture and forestry sectors, as well as some on-farm energy emission reductions. Yet they leave on the table substantial potential for additional GHG mitigation from on-farm activities in the agriculture and forestry sector, which is second only to energy as a source of global GHG emissions.

In this paper, we report the official U.S. estimates of agriculture and forestry mitigation potential that could have been achieved with implementation of H.R. 2454, the cap and trade proposal passed by the House of Representatives in 2009. We compare it against the official estimates of agriculture and forestry mitigation achieved by agriculture and energy policies, and proposed energy sector alternatives to the multi-sector cap and trade program. Our underlying purpose is to assess to what extent energy and agriculture sector policies can provide mitigation incentives comparable to the cap and trade legislation. The energy sector policies, which promote bioenergy, include the current federal Renewable Fuels Standard (RFS2), which mandates increasing levels of biofuel blending into the fuel supply through 2022, and two policy proposals targeting electricity generation, including clean energy portfolio standards and regulation of new sources under the Clean Air Act. The agricultural

[1] The views expressed are the authors and should not be attributed to ERS or USDA.

policies we consider are conservation programs and agricultural R&D – neither of which was designed as greenhouse gas mitigation policies. Synthesizing estimates from the literature and from our own analyses, we identify how far short the mitigation potential of current and proposed energy and agricultural conservation policies is, relative to the potential with cap and trade. Part of the differential is due to lack of budget to accomplish the scale of mitigation achievable with cap and trade. But another part of the differential is due to current program design, which misses significant opportunities for mitigation, including afforestation of crop lands, as well as various categories of best management practices on working lands.

2. U.S. Agriculture and Forestry: Greenhouse Gas Profile and Mitigation Options

Forest and agricultural land uses encompass 89 percent of all land in the continental U.S., with 35 percent in forest, 33 percent in pasture and range, and 21 percent in cropland (Nickerson et al 2011).[2] In 2008, agriculture and forestry contributed around 8 percent of total U.S. gross CO_2e emissions (including energy use), while net additions to carbon soil or biomass sinks in agriculture and forestry –through land use change and land management activities that sequester carbon in soils or biomass – offset 13.5 percent of U.S. gross emissions (see Figure 1).

The profile of current GHG emissions from agriculture, forestry and land use (AFOLU) differs substantially from the profile of other sectors. Carbon dioxide emissions, predominantly from energy combustion, represent 85 percent of total U.S. GHG emissions (in metric tons CO_2e). In contrast, agriculture and forestry have unique crop and livestock sources of nitrous oxide (N_2O) and methane (CH_4), which dominate its emissions profile; as a result,

[2]The remaining land uses are settlements (6 percent), wetlands (3 percent) and other (2 percent).

CO_2 emissions from energy use emissions represent a small share of total sector emissions (15 percent, relative to 46 percent and 39 percent for N_2O and CH_4, respectively). The agricultural activity generating the most emissions is soil management, substantially due to emissions from the use of nitrogen-based fertilizers; over 70 percent of the soil emissions are from cropland, the remainder from pasture land (figure 1). The next largest source is livestock animal management, with enteric fermentation (digestion in ruminant livestock) emitting methane, and manure management emitting both methane and nitrous oxide. The remaining agricultural category is energy-related emissions of carbon dioxide from on-farm fossil fuel use to support machinery use, irrigation, and crop drying, or from distributed electricity generation. Forestry emissions, a small part of the sectoral total, are primarily from forest fires.

In terms of carbon sequestration for current AFOLU activities, two activities -- land use change from agricultural to forest land (afforestation) and forest management on continuing forest lands –currently generate the most sequestration (the two activities are combined in the “Forest C-sink” category in figure 1). A much smaller amount of sequestration occurs from land-use change to grass lands and on lands continuing in grass and crop uses. Land-use change to cropland is a net source of carbon emissions, but sequestration on continuing croplands is a slightly greater sink of carbon; as a result, on net, a small amount of sequestration accrues to croplands (crop, pasture C-sink in figure 1).

There are two primary classes of agriculture and forestry mitigation strategies: (1) adopting production technologies that lower GHG emissions and increase carbon sequestration, and (2) supplying bio-based substitutes for fossil fuel feedstocks to produce energy – either for transportation fuels of for power and heat. We consider each in turn.

Agriculture and forestry activities with the highest technical potential for GHG mitigation are those that sequester carbon in biomass or the soil. At the top of the list are afforestation of cropland and pasture land, and management of land in forestry uses. Activities with the highest technical potential to sequester carbon on land remaining in crop and pasture uses include improved grazing management, use of winter cover crops, adoption of conservation tillage on cropland[3], and land use change from cropland to perennial grasses.

Wetland restoration also has been considered a potential GHG mitigation activity. However, because wetlands in North America are highly variable, a recent panel of experts concluded that current data are insufficient to determine the direction of the effect of wetland restoration on net GHG emissions; the panel did note that the highest potential for mitigation was in northern latitude wetlands, including prairie potholes (Eagle and Sifleet 2011).

Though emissions from N_2O and CH_4 dominate total agricultural and forestry sector emissions, activities that primarily reduce N_2O or CH_4 emissions generally have lower technical mitigation potential. One crop-related activity is improved fertilizer management (e.g., reducing application rates and using slow-release fertilizer or nitrification inhibitors), which reduces N_2O emissions from soils.[4] Changes in livestock management that focus on the reduction of methane emissions and biogas capture (e.g., improved diet and improved manure management) also offer mitigation potential; however, some manure management approaches (such as handling manure in solid form, via composting) may increase N_2O emissions.

[3]Conservation tillage includes practices that reduce the level of soil disturbance relative to traditional moldboard plowing. Reduced tillage practices involve tillage in a lesser proportion of the row or tillage is limited to just prior to planting. No-till only cuts into soil enough to plant the seeds.A panel of scientific experts indicated general agreement that changing from conventional tillage to no-till results in net GHG mitigation for most regions of North America, whereas the direction of the effect for reduced tillage is less certain (Eagle and Sifleet 2011).

[4]In some cases, a corollary benefit may be some additional carbon sequestration (Eagle and Sifleet 2011). Reduction in fertilizer use also reduces CO_2 emissions from manufacturing fertilizer.

The size and direction of GHG impacts associated with the second class of mitigation strategies - substituting bioenergy for fossil-fuel-based energy –is the subject of substantial discussion and controversy, due primarily to uncertainties about the scale of indirect land use change induced by production of agriculture and forestry-based feedstocks. Substituting biomass for fossil carbon, such as petroleum and coal, to produce liquid fuels or electricity can reduce GHG emissions under certain conditions. The logic underlying the substitution is that combustion of biomass releases carbon dioxide that already is part of the global cycle of biogenic carbon in active circulation, whereas combustion of fossil fuels releases carbon dioxide not previously in active circulation. As a result, combustion of fossil fuels increases the total amount of carbon circulating among the terrestrial, atmospheric and oceanic carbon pools, whereas combustion of biomass does not.

To compare GHG impacts over time across the alternative fossil fuel and biomass energy sources requires careful intertemporal accounting of all of the emissions across the lifecycles of each – including feedstock production, transport, and distribution, as well as fuel production and combustion. The GHG implications of biomass-based energy will vary depending upon type of feedstock (residue/waste products vs. biomass grown for bioenergy; and among produced biomass, starch/sugar-based vs. cellulosic, annual vs. perennial crops, etc.) For feedstocks originating from additional crop production, questions have been raised about how much land will be converted in order to produce feedstocks (direct land-use change) or to produce crops displaced by production of feedstock crops (indirect land-use change), and how large will be the resulting carbon releases relative to the gains in lower annual emissions from substituting biofuels for fossil fuels.

When considering the contribution of AFOLU mitigation activities, it is important to bear in mind two aspects of activities that sequester carbon, which do not occur with activities that reduce GHG emissions. First, to be equivalent with emissions reduction, the activity sequestering the carbon must be maintained for a period equal to the time carbon remains in the atmosphere after release – a state referred to as "permanence."[5] Alternatively if the sequestering activity, such as conservation tillage, is terminated and all or part of the sequestered carbon is released as a result, a full GHG accounting for the activity would reflect the extent to which previously sequestered carbon has been released.

Second, after adoption of a new management practice or land use that sequesters more carbon, terrestrial systems tend to move toward a new equilibrium carbon stock, causing a diminishing annual sequestration over time. Carbon stocks and potential rates of accumulation vary significantly across ecosystems with land use, management practices, geographical location and local environmental factors, such as climate and soil characteristics. Due to past management practices, most U.S. agricultural soils have relatively depleted stocks of carbon, compared with native ecosystems, and thus can readily respond to land- management practices that promote carbon sequestration. For example, when cultivated cropland is converted to grassland, soil carbon typically accumulates for a few decades (Paustian et al. 2006).

3. Economic Mitigation Potential: Proposed Multi-Sector GHG Cap and Trade Policy

The most comprehensive federal climate mitigation policy seriously debated in the U.S. Congress is a program to cap and trade GHG emissions across the economy.[6] Though the U.S. House of Representatives passed the American Clean Energy and Security Act of

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[5] Fifty percent of a carbon release will remain in the atmosphere 100 years later.

[6] A cap and trade program establishes a limit on total allowable emissions per unit of time for all sources covered by the cap. The total emissions cap is then allocated to covered firms in the form of allowances that can be freely exchanged among sources in a decentralized process, without approval at the program level. By allowing trading of allowances, a cap and trade program can achieve cost-savings relative to traditional regulations by allowing high-cost sources to buy, and low-cost sources to sell, allowances representing their allotted share of the cap.

2009 (H.R. 2454),[7] parallel legislation stalled in the U.S. Senate in 2010.[8]In this section, we present the official U.S. government estimates of the potential for agricultural sector GHG mitigation projected for the cap-and-trade legislation passed by the U.S. House of Representatives. The analysis takes as given the future path of mitigation projected for policies currently in place, including the biofuel blending mandate, and the agricultural conservation, income support and R&D policies we consider in the following sections.

3.1 Recent Legislative Deliberations

The American Clean Energy and Security Act of 2009 (hereinafter referred to as H.R. 2454) defined a federal cap and trade system for greenhouse gas emissions, where the cap would reduce covered greenhouse gas emissions to 17 percent below 2005 levels by 2020, and 83 percent below 2005 levels by 2050. None of the proposed federal legislation included agriculture and forestry among the sectors covered by the emissions cap; however, most – including H.R. 2454 – include agriculture and forestry as a potential source for GHG emission offsets.[9]

EPA's economic analysis of the program estimated that, with trading (including domestic and foreign offsets and banking and borrowing), the declining cap on allowable

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[7]See http://www.govtrack.us/congress/billtext.xpd?bill=h111-2454 (Accessed July 8, 2011.)

[8]Currently, a range of multi-sector GHG mitigation policies are operating or are in development at the state and regional level, plus several voluntary carbon markets are active. The Regional Greenhouse Gas Initiative (RGGI), operational since 2009, created a cap and trade program for carbon dioxide emissions from power plants in ten Northeastern and Mid-Atlantic states (from Maine to Maryland), though the governor of NJ announced NJ's withdrawal in 2011. California has the most ambitious program: it recently adopted rules to implement a mandatory cap and trade system starting in 2012 with emission reductions back to 1990 levels by 2020 and 80 percent below 1990 levels by 2050. The approved rules include provisions allowing the use of offset credits stemming from uncapped sectors, including forestry and agriculture, within the U.S. as well as internationally. Other climate policies adopted by various states include GHG emissions targets and climate action plans. In addition, various voluntary markets have been active. (See http:/www.c2es.org/states-regions, and Kossoy and Ambrois, 2011).

[9]Introducing the opportunity to purchase offsets from entities in uncapped sectors provides those subject to the cap with additional options for lowering the costs of meeting their compliance obligations. In an offset program, unregulated firms voluntarily choose whether to earn offset credits for sale by adopting specific activities or projects that reduce emissions relative to a baseline level of emissions.

emissions over time could be met at a private cost of $14 per mt CO_2e in the 2020-2029 decade, rising to $70 per mt CO_2e in 2050-2059 decade. As the cap declines over time, the entities covered by the cap are projected to purchase more agricultural and forestry offsets.

The relative contribution to mitigation of different agricultural and forestry activities changes over time, as the price rises. Mitigation from forest management dominates at the lower prices in the early years, while afforestation surpasses forest management after the 2030-2039 decade. See figure 2 and table 1. Relatively small, but increasing over time, are the estimated emission reductions from cropland management (particularly N_2O from fertilizer and CH_4 from rice production) and livestock management (CH_4 and N_2O from manure and enteric fermentation). Sequestration of additional soil carbon on cropland is limited because more of the economic potential has been captured by USDA's conservation programs. The total annual purchases of domestic offsets from forestry and agriculture are estimated to increase from 176Tg CO_2e per year in the 2020-2029 decade, to over 643 Tg CO_2e per year in the 2050-2059 decade. Because fossil fuel emissions fall under the cap, reductions in energy-based emissions are not included in the offset accounting. Abatement of fossil fuel emissions (generated either directly by agriculture or forestry production, or by their input suppliers) and substitution of bioelectricity for fossil fuel sources add an additional 2 and 9 percent to agriculture/forestry mitigation, respectively, in 2020-2029, increasing to 3 and 15 percent, respectively, in 2050-2059.[10] Bioelectricity is consistently the third most significant source of abatement, and its share of abatement increases over time as GHG prices rise and biomass feedstock yields increase.

[10] US EPA 2009. Data Appendix, HR 2454 June 23, 2009 analysis. (worksheet: HR2454 Data Annex\ ADAGE & IGEM v2.3.xls)

In 2010, the U.S. Senate deliberated on the American Power Act (APA), though ultimately did not pass it. Key features of APA and H.R. 2454 are the same – for example, the percentage reductions represented by the emissions caps are identical beginning in 2013, and both bills allow for 2,000 Tg of CO_2e offsets in each year. The modeled impacts of APA are very similar to those of HR2454: notably, the estimated allowance prices under the two bills differ on the order of 0-1 percent. Further, the contributions from forestry and agricultural domestic offsets are similar.[11]

3.2 Caveats to Estimates of Agriculture and Forestry Offsets

The estimates from the EPA analysis are sensitive to several factors. For one, the modeling may underestimate agricultural and forestry mitigation potential, to the extent that it did not account for several categories of potential agricultural GHG reductions that may be included in federal legislation, including improvements in organic soil management, advances in feed management of ruminants, changes in the timing, form, and method of fertilizer applications, and alternative manure management systems – other than anaerobic digesters, which are included. Perhaps most important is that the EPA analyses (2009a, 2010c) implicitly assume that participation by agriculture and forestry is mandatory. In reality, participation in offset markets - by suppliers of allowances and those not covered by the cap - is voluntary, and farmers are not expected to choose to reduce emissions in order to supply offsets unless it is profitable to do so. Studies analyzing data on observed farmer adoption rates for voluntary conservation programs indicate that adoption rates tend to be lower than

[11]One difference in the offset provisions is that the APA allows offsets for methane from landfills, natural gas and coal mines, whereas HR 2545 subjected them to performance standards; as a result, allowance prices are slightly higher and GHG emissions from capped sources are slightly higher.

suggested by ex ante optimizing models (with profit-maximizing farmers), such as employed in this analysis.[12]

With a voluntary program, the selling of allowances (which encourages sequestration and discourages emissions) only occurs by enrolled landowners during the period in which they agree to participate. As a result the analysis understates the potential for emissions **leakage** from non-enrolled suppliers in the market or carbon sequestration **reversals** by enrolled landowners after their participation period ends (see box below for definitions of bolded terms and further discussion of the environmental integrity issues that arise in designing an offset program).

Some insights about the extent of GHG leakage with a voluntary, rather than mandatory, offset program can be gained from a recent study. Latta et al. (2011) found that with respect to forestry activities, the enrollment of private forested land in a voluntary program would be substantially less than for a mandatory one, and the estimated quantities of carbon sequestration would be lower at all prices examined.[13] At the $5 per ton price, a voluntary program generated about 1/3 of the afforestation and 1/6 of the forest management mitigation generated by a mandatory program. At $30 per ton, a voluntary program generated about 40 percent of the afforestation and forest management mitigation as a mandatory program.[14]

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[12]Transactions costs, which are not directly observable, serve as a brake on adoption, as may the ownership status of the land. The model does not capture these factors: it does not differentiate between owned or rented land, and the only transactions costs associated with program participation included in the model are the costs of land conversion. See Latta et al, 2011, for a discussion of the literature.

[13]Lewandrowski et al. (2004) compared voluntary and mandatory offset programs with a 15-year commitment period for agricultural mitigation. Using a comparative static model of the agricultural sector, the analysis was able to capture afforestation but not the full set of forestry mitigation activities. Similar to Latta et al, (2011) the study found that an incentive system that includes both payments for GHG emission reductions/carbon sequestration and charges for GHG emissions resulted in substantially more mitigation than did a system with payments only.

[14]The analysis is not directly comparable because the EPA analysis of the legislation assumed GHG prices increase over time at 5 percent per year, whereas this study assumed constant prices over time.

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[BOX] Challenges to Environmental Integrity in GHG Mitigation Programs

To ensure that GHG mitigation activities produce real reductions, several factors need to be considered when estimating the resulting total net reduction in GHG. These issues arise in the accounting for GHG emissions associated with voluntary GHG offsets, mandatory biofuel production, and voluntary conservation programs discussed below.

- **Leakage** occurs when a GHG-mitigation activity (such as producing biofuels under mandate or setting aside cropland under a conservation program) displaces GHG-emitting activities to other sectors or geographic locations not within the scope of the program, or – in the case of a voluntary program -- to eligible sources that have chosen not to enroll. As a result, the additional GHG emissions from the displaced activities offset, at least in part, the activity-based emission reductions. For example, a program that compensates farmers for converting highly erodible crop land to grass land may induce other land to be cleared for agriculture. When calculating the net GHG impacts of a program, a full accounting of impacts would include increases in emissions from any shifts in the location of activities as a result of the program. It is important to note, however, that identifying and attributing those activity shifts to a specific source is challenging, particularly if they occur outside the country. The limited empirical studies on the topic suggest that voluntary participation in forest land preservation (taking it out of production) is most likely to induce compensatory planting elsewhere and therefore to generate substantial leakage; cropland conversion to grassland is likely to generate less leakage because conversion tends to occur on lower productivity land; and finally, adoption of land management practices such as conservation tillage or reduction in fallow crops is least likely to reduce crop supply on participating land and generate a compensatory response, and associated emissions leakage (Murray et al. 2007).

- **Additionality**. The additionality of net GHG emission reductions signifies that the reductions are *beyond* what would have occurred under business-as-usual conditions without the program (i.e., the baseline). For example, if a farmer would have adopted no-till without being compensated, then the GHG emission reductions from no-till adoption as a conservation program participant are not additional. Conversely, if a farmer would have abandoned conservation tillage without the program, then continued conservation tillage would be additional. Constructing such an emissions baseline into the future is challenging, because it involves forecasting future behavior in the absence of the proposed policy. Included in the baseline level of emissions are requirements imbedded in current policy, which may be changing over time (such as increasing levels of mandated biofuel consumption from 2007 through 2022).
- **Carbon sequestration reversals (lack of permanence)**. With the termination of carbon-sequestering activities such as conservation tillage or forest land use, not only does the sequestration stop (as occurs when an energy-efficiency technology is terminated), but - in addition - the carbon sequestered during an earlier time period will be released. A full accounting of the GHG impacts of a program would include the increases in emissions resulting from any future reversals of the sequestering activities.
- **Carbon-stock re-equilibration.** Over time and under relatively constant environmental and management conditions, rates of carbon additions and emissions tend to equilibrate and the amount of organic carbon in soils stabilizes at a constant or steady-state level (i.e., the carbon-stock equilibrium). If the relationship between additions and losses changes due to a change in soil management or land use, the soil will gradually

move to a new carbon-stock equilibrium, at which point additional sequestration (or emissions) will cease.

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4. Economic Mitigation Potential: Energy Sector Policies

Following the demise of national-level cap and trade legislation, the policy discussion at the federal level shifted to target a broader set of goals -- including energy security, economic competitiveness, and cleaner air, along with climate change mitigation -- with a more narrow set of energy sector policies. Energy sector policies can affect mitigation in agriculture and forestry by providing incentives to reduce on-farm fossil fuel combustion (and the use of energy-intensive inputs, such as fertilizers), as well as to supply biobased alternatives to fossil fuel feedstocks. At the GHG prices forecast for HR2454, the quantity of on-farm energy-related mitigation is relatively small. Whether a comparable scale of reduction will be achieved with alternative energy policies will depend upon whether the policies induce a comparable increase in energy prices as would occur with cap and trade.

In recognition of the mitigation uncertainties associated with substituting bioenergy for fossil-based energy, the 2007 biofuel mandate imposes several sustainability conditions to promote likelihood that mitigation gains are achieved. And in proposed electricity regulations, decisions about the GHG accounting for lifecycle emissions from biomass feedstocks, including agricultural waste, landfill wastes, and dedicated energy crops, needed to make regulatory decisions about bioelectricity are being delegated to expert sources.

4.1 Biofuels: U.S. Renewable Fuels Standard

Numerous policies, in tandem with high energy prices during the last decade, have stimulated the development of the biofuel sector over the last four decades. Though a blenders tax credit (introduced in 1978) and the complementary tariff on foreign imports of ethanol (introduced in the 1990s) were terminated at the end of 2011, the legislation mandating annual increases in the volumes of U.S. renewable fuel consumption remains in place. The Energy Policy Act of 2005 (EPACT) created the first national Renewable Fuel Standard (RFS), which mandated domestic use of 7.5 billion gallons of biofuels by 2012.[15] Two years later, the Energy Independence and Security Act of 2007 (EISA) greatly expanded the biofuels blending mandate to 36 billion gallons of total renewable fuels per year by 2022, with a set of nested volume requirements for sub-categories of renewable fuels, each with its own sustainability provisions.[16]

Of the total renewable-fuel requirement for each year in the new mandate (RFS2), a maximum is imposed on the volume that can be supplied with conventional biofuel (corn-based ethanol meeting the sustainability condition). The remainder of the total renewable fuel volume mandate must be met by "advanced biofuels" such as cellulosic biofuels and biomass-based biodiesel. However, the advanced biofuels requirement, and its cellulosic and biomass-based components,are subject to adjustment by EPA each year, based on its assessment of available commercial production capacity. Under this authority, in both 2010 and 2011, EPA lowered the cellulosic mandates; however, it has approved as advanced biofuels several fuels made from conventional feedstocks (ethanol from sugar cane, biodiesel from soybean oil, and renewable diesel from waste oil, fats and grease), and consequently it retained the full volume mandate for total advanced biofuels and for total renewable fuels (U.S. EPA 2010c).

In the assessment, EPA accounts for GHG emissions across the life-cycle of the biofuel supply chain, including feedstock on-farm production and logistics, and biofuel

[15]Ethanol, the most prominent biofuel, began commercial–scale production in large part due to a blenders tax credit created under the Energy Policy Act of 1978. Another more recent policy stimulus to ethanol production was the effective ban on methyl tertiary butyl ether [MBTE] as an oxygenate in gasoline, on air quality grounds in EPACT (Babcock, 2008).

[16] See EPA 2010 for an excellent explanation of the legislation and the subsequent EPA rules implementing the legislation.

production, distribution and use. As noted above, the life-cycle analysis of the GHG emissions in the regulatory impact analysis for the rule has been very controversial, particularly due to uncertainties in forecasting global indirect land use change based on current land use models.

According to EPA's regulatory impact analysis estimates, use of RFS2-mandated renewable fuel quantities in 2022, relative to U.S. Department of Energy (2007) market projections for 2022 without the mandate, will displace about 13.6 billion gallons of petroleum-based gasoline and diesel fuel -- about 7 percent of expected annual gasoline and diesel consumption in 2022. In the RFS2 scenario, cellulosic biodiesel and cellulosic ethanol are assumed to provide 6.5 and 4.7 billion gallons, respectively, of the total of 36 billion gallons mandated renewable biofuel use in 2022. Estimated emission reductions for those two biofuels, relative to the petroleum fuel baseline, range from -72 percent to -129 percent. Under the assumptions maintained in the analysis, the payback period for the ethanol portfolio mandated for 2022 is estimated to be a little over 2 years, and the net annual impact is to reduce GHG emissions by an estimated 138 Tg CO_2e relative to a no-mandate reference case (Table 1).

Some uncertainties exist in the feasibility of meeting the mandate in 2022. The timing of the commercialization of new technologies, including cellulosic, to produce biofuels cannot be determined due to various uncertain factors. However, EPA has approved sugar ethanol and soybean-oil-based biodiesel as advanced biofuels, so it may be possible to meet a greater share of the advanced biofuel volume mandate with imports of sugar-based ethanol from Brazil, combined with domestic production of soybean-based biodiesel. Future developments also will depend upon new investments in infrastructure and the vehicle fleet because, as the mandate volumes increase over time, it will become increasingly difficult to absorb them into the transportation sector as it is currently structured (Coyle 2010).

4.2 Renewable/Clean Energy Standards with Tradable Permits

Current market and policy drivers for the expansion of bioelectricity include high fossil fuel prices, as well as Federal tax incentives and grants (many of which are set to expire between the end of 2012 and 2013, such as the Federal production tax credit and energy tax credits) and an extensive set of state renewable/clean energy programs. Proposals for federal level regulations exist on two fronts. On March 27, 2012, the U.S. EPA proposed a carbon pollution standard for new electric power plants, as required under the Clean Air Act (CAA), as clarified by the U.S. Supreme Court in Massachusetts v. EPA.[17] However, EPA held off in proposing regulations deciding under what circumstances biogenic feedstocks may qualify a plant as best practice under the CAA, pending review by expert panels yet.

In addition, both the President and members of Congress have put forth concepts for a federal clean energy standard (CES) that would double, from 40 to 80 percent, the share of electricity generated from "clean" energy sources by 2035, including partial credit for fossil fuels with CCS and for efficient natural gas.[18] The first bill to be introduced in 2012, Senator Bingaman's Clean Energy Standard Act[19], defers decision-making about crediting for biogenic feedstocks to an expert panel.

Choices regarding key design features – including what counts as clean energy, who is covered, how is the base quantity of electricity sales defined - can significantly affect the

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[17]The new CAA proposed regulation under the CAA for regulating GHG emissions from new sources does not cover co-firing or dedicated biomass electricity generation plants. EPA has set a schedule for promulgating regulations that cover under what circumstance electricity generation from biomass feedstocks may qualify a plant as BAT.
[18]Ibid.
[19]http://energy.senate.gov/public/index.cfm/files/serve?File_id=b3580f37-ec8c-4698-a635-3e19f9815b9a

projected mitigation potential. In the Bingaman proposal, annual clean energy targets[20] ramp up linearly from the current level (24 percent) to 84 percent in 2035. The analysis assumed zero emissions from biogenic feedstocks, so the analyses provide an indication of the scale of bioelectricity that would occur under the most inclusive treatment of biobased feedstocks.

According to the EIA analysis[21], the Bingaman proposal would increase biomass and wind the most among the renewable technologies. The biomass share increases more than sixfold, from 1.0 percent in 2009 to 6.6 percent in 2025 (not quite double the 2025 reference level), but then remains at a fairly constant level (and declining share) in 2035. All of the growth in biomass use relative to the reference case is attributable to co-fired generation, which begins to decline at the end of the period, as coal-fired plants that co-fire biomass are retired.

A salient question is, how do the changes in electricity from biomass sources projected for the CES policy compare to those projected for the cap and trade policy (H.R. 2454)? For greater comparability of analytical tools and approach, we compare the EIA analyses of the two policies. For 2025, the projected change in biomass generation levels (B kWh) between the reference case and the policy is slightly higher (10 percent) with H.R. 2454 relative to the Bingaman clean energy standard, though in the former the biomass generation levels for both the reference and policy case are lower than for the CES. A further divergence opens up beyond 2025: in the EPA analysis of H.R. 2454, the level of generation from biomass continues to increase through 2035, and on through 2059, as GHG prices increase and biomass feedstock yields improve. The difference is attributable in part to EIA revisions

[20] All generation from existing and new wind, solar, geothermal biomass, municipal solid waste, and landfill gas earns full credits; hydroelectric and nuclear generation placed into service after 1991 earn full credits. Partial credits are earned for generation using specific technologies fueled by natural gas or coal, based on a calculated crediting factor that reflects the carbon intensity of each technology.

[21] EIA, 2011a; EIA 2011b.

between 2009 and 2011 in the cost structure for biomass generation, so that dedicated energy crop plants no longer are economic compared to other clean energy alternatives.[22] In addition, the difference reflects an increasingly higher level of incentives for reducing GHG emissions under the cap and trade policy.

5. U.S. Agricultural and Forestry Conservation Programs

In this section we describe federal conservation programs administered by the U.S. Department of Agriculture (USDA), and discuss their potential contribution to GHG mitigation. With projected total net outlays of $24 billion, conservation programs collectively comprise about 8 percent of Farm Bill outlays over 2008-2012 (Monke and Johnson 2010).[23,24] Whereas the analysis of GHG impacts of conservation programs typically focuses on on-site impacts of currently enrolled land, we also consider the additional elements needed for a more complete GHG accounting of cumulative program impact: the flows of land in and out of the program, and their changing land use and potential feedback effects on land never enrolled. These patterns have implications for additionality, leakage, reversals and carbon re-equilibration.

[22] Personal communication, Christopher Namovicz, EIA.

[23] Most of USDA funding for federal conservation, commodity and farm support policies, as well as other rural, food, and farm-related provisions, derives from multi-year, omnibus laws "farm bills", which must be renewed every 5 years. The 2008 Farm Bill is formally known as the Food, Conservation, and Energy Act of 2008.

[24] USDA also administers a number of agricultural commodity support and crop insurance subsidy programs that are designed to increase the returns, or reduce the downside risks of low returns, from agricultural production. These programs have the potential to induce producers to bring additional land into crop production when they make cropping profitable where it would otherwise not be – in other words, counteracting GHG mitigation provided by USDA's conservation programs, by releasing carbon sequestered in the soil and increasing GHG emissions from fertilizer and other inputs. In general, quantifying the land use impacts of these programs is quite difficult due to challenges in identifying the impacts of program payments separately from the impacts of the various other factors that affect land use decisions e.g., Gardner, Hardie and Parks 2010; Bhaskar and Beghin 2009).

5.1 USDA Conservation Programs

The vast majority of USDA conservation programs promote conservation on cropland and pasture or range lands. Though GHG mitigation represents only one of several environmental goals of the conservation programs, many of the practices supported by the programs tend to promote GHG mitigation. However, as discussed in section 2, the effects vary across the landscape and substantial uncertainty remains regarding the scale, and even the direction, of the GHG effects of many activities in specific locations. However, several of these programs do provide some support for afforestation, or for enhanced forestry practices on nonindustrial private forest lands.[25]

Conservation Reserve Program

Virtually all of the mitigation potential attributable to federal conservation programs stems from lands enrolled in the Conservation Reserve Program (CRP). CRP is – by far – the largest U.S. conservation program in terms of hectares enrolled and budget. It provides annual rental payments over a 10-15 year contract period to farmers who voluntarily retire environmentally-sensitive cropland from production, as well as cost-share assistance for establishing approved grassland or tree cover on the enrolled land. Enrolled land area has fluctuated between 12.1 – 14.9 million hectares, after initial implementation during the first five years of the program 1986-1990. In 2008, 14 million hectares were enrolled in the CRP at an approximate annual rental cost of $1.8 billion (averaging $125.4/ha) (USDA–FSA

[25]One program that does focus on forestland, the Forest Legacy Program, authorizes federal acquisition, or grants to states for their acquisition, of lands or permanent easements on private lands threatened by conversion to non-forest uses. As of February 2010, the program has placed into easements 0.8 million hectares of forestland in 42 States and Territories. See http://www.fs.fed.us/spf/coop/programs/loa/flp_projects.shtml

2008).[26] The 2008 Farm Bill reduced maximum enrollment to about 13 million hectares beginning October 2009.

The retirement of cropland and its conversion to pasture is one of the few land use/land management activities for which there is general scientific agreement that the technical potential exists for positive GHG mitigation benefits (Eagle and Sifleet 2011). CRP funds several land retirement practices that sequester carbon, including planting the land to grasses, planting the land to trees, and restoring wetlands. For contracts in effect in 2008, 12.4 million ha (88 percent) were planted to grasses, 1.5 million ha (10.5 percent) were planted to trees and about 0.2 million ha (1.4 percent) were restored wetlands. These enrolled lands increased carbon sequestration annually by an estimated 430 Tg of CO_2e, plus reduced an additional 9 Tg CO_2e of emissions due to reduced fuel and fertilizer use (Table 1). These estimates are based solely on GHG implications on currently enrolled lands. The potential GHG mitigation from voluntary land retirement in CRP is smaller relative to mitigation from regulatory measures (i.e., RFS2 estimated at 138 Tg/yr CO_2e in 2022) and H.R. 2454 (estimated at 196 Tg/yr in 2020, rising to 782 Tg/yr CO_2e in 2050).

Questions about additionality, leakage, and post-CRP land use decisions help explain why the net potential for positive GHG benefits from CRP activities is expected to be even more limited (see Box for a discussion of these terms). Lubowski et al. (2008) estimate that 15 percent of CRP land enrolled through 1997 would have been converted from crops to pasture, range, or forests even in the absence of CRP, due to economic considerations. Efforts to estimate leakage of agricultural land have been inconclusive: estimates of the share of land

[26]Of the CRP enrollments in 2008, about 12 million hectares were enrolled through competitive signups (not all land that farmers offered to retire was accepted into the program) at a rental cost of about $108/ha. An additional 1.6 million ha with high priority conservation practices such as filter strips and riparian buffers were enrolled without competition, at an average rental payment of $247/ha. Another nearly .1 million ha of farmable wetlands were restored at an average rental payment of $289/ha (USDA-FSA 2008).

enrolled in the CRP that was replaced in production elsewhere by land conversion from some other use to cropland range from 20 percent (Wu 2000, 2005) to 53 percent (Leathers and Harrington 2000), depending on the estimation method and the geographic and temporal scope of the analysis. However, Roberts and Bucholtz (2006) raise questions as to whether it is feasible to statistically identify land leakage.[27]

When calculating net mitigation impacts of the CRP, the carbon releases from returning land to crop use must be deducted from the carbon gains from current period enrollments.[28]Little is known about how land exiting the CRP is used, however. The carbon sequestration implications after a contract expires can be positive, neutral or negative. On the one hand, if the land is not returned to cropland, additional carbon may continue to be sequestered until a new carbon-stock equilibrium is achieved. On the other hand, if the land is returned to cropping, not only will carbon sequestration stop, but also the carbon sequestration gains from program participation in prior periods may be reversed.

To provide insights into uses of CRP land after exiting the program and to estimate likely carbon releases from post-CRP land use decisions, we use USDA's National Resources Inventory data[29] to analyze subsequent uses of CRP land that exited the program during 1992-1997. We consider land uses over a 15 year period after CRP exit (the longest period possible). Of 13.8 million hectares in CRP contracts as of 1992, 1.4 million hectares had exited the CRP by 1997. Of the 1.4 million hectares exiting, .8 million hectares (55% of

[27]We also note that to estimate the GHG emissions leakage that results from land leakage requires an additional step – since the land entering and leaving production may sequester carbon and emit nitrous oxide from fertilizers at different rates.

[28]In contrast, the emission reductions in prior periods due to lower fertilizer use with conversion to grasslands are not subject to reversals; consequently when the land is returned to cropping, the credits for reduced N_2O stop, but no deductions against past credits are needed.

[29]USDA's National Resources Inventory is a survey of all non-Federal land that was conducted every 5 years between 1982 and 2002, and then annually (on a subset of fields) through 2007. Because the same fields are sampled over time, land use transition matrices can be constructed to identify post-CRP land use decisions.

expired land) converted to cropland within 15 years after exiting, and .01 million hectares (less than 1%) converted to developed uses. The remaining lands were in uses that would have relatively limited carbon releases: hay, fallow, set-aside, pasture/range or forest uses. This is consistent with research that has found there are rigidities in changing land uses after exit from CRP, suggesting not all GHG mitigation attributable to the CRP will be reversed upon exit (Roberts and Lubowski 2007). About .2 million hectares were re-enrolled in the CRP, though some of this land was cropped before re-enrollment (.06 million hectares).

The carbon releases of CRP lands converting upon exit to cropland and development will vary based on the type of vegetative cover planted while the land was enrolled, and – for land subsequently cropped – the crops and tillage practices adopted. The vast majority – .78 million – of the .81 million hectares of land converting to cropland and development by 2007 had been planted to grasses or legumes when enrolled in CRP. Another .02 million hectares had been planted to trees. Carbon releases are greater the more intense the tillage practice that is adopted, at least for most soil types. Adoption of continuous no-till may conserve previously sequestered SOC (Follett *et al.* 2009), while many other studies show that conventional tillage can result in the loss of most or all carbon sequestered while the land was enrolled in CRP (e.g., Gilley and Doran 1997). If we conservatively assume that conventional tillage was adopted on all post-CRP land that was cropped (so that the estimate of net mitigation benefits of CRP are not overstated), our analysis suggests that consideration of subsequent land use decisions and tillage choices of CRP land would reduce the GHG sequestration impact of CRP by a relatively small amount, 1 Tg/yr.[30]

[30] The estimated reduction due to post-CRP land use decisions and tillage is not intended to be exact, but for illustrative purposes of the likely scale of the impact. The estimated .001 Gt/yr reduction is derived by calculating a per-ha-sequestration estimate for enrolled grassland soils, and multiplying this by the .78 million acres of grassland that was converted to cropland over a 15 year period 1992-2007. This assumes that all soil sequestration is lost due to post-CRP tillage choices.

Two factors are likely to reduce the future ability of CRP to sequester GHG at historical rates. First, high commodity prices since 2007 have made cropping a more attractive alternative for some landowners, and fewer acres have been offered for enrolment.[31] Second, the growing Federal deficit has led to Congressional discussions about reducing Federal government program budgets, including for CRP. Taken together, these factors suggest that CRP's ability to sequester carbon in the future could decline significantly.

Other Conservation Programs

The Wetlands Reserve Program (WRP) offers financial assistance to restore, enhance and protect wetlands on land retired from agriculture, and on some lands, purchases permanent or 30-year easements for the wetlands. WRP had over .8 million hectares enrolled through 2008 and is capped at a total enrollment of about 1.2 million hectares (USDA-NRCS 2008). While wetland restoration activities funded by WRP have potential to provide GHG benefits, the direction of the net GHG impacts can vary across different types of soil, past uses, and wetland types, as noted above (Eagle and Sifleet 2011). Indeed, a recent study did not find statistically significant increases in carbon stocks associated with wetland restoration projects funded by WRP (and, to a lesser extent, CRP) (Gleason et al. 2008). Any GHG benefits that arise from wetland restoration could only be attributed to the WRP to the extent the restoration is additional and does not result in land conversions elsewhere (leakage). To our knowledge, no studies have examined these additionality or leakage considerations related to WRP enrollments. In terms of permanence, about 85 percent of WRP contracts are under permanent easements, so potential GHG mitigation from restoring wetlands would not be reversed.

[31]During the 2007-2010 period, a significant percentage of enrolled land – 11.38 million hectares – was in contracts set to expire at a time of relatively high commodity prices, in part due to growing demands for ethanol feedstocks. Yet, by offering current contract holders priority to re-enroll with 10-15 year contracts or to extend their contracts for 2-5 years, USDA-FSA was able to re-enroll or extend 82 percent of expiring contract land

The Grassland Reserve Program (GRP) purchases contracts or easements on grazing lands that otherwise could be converted to cropland or developed land, in order to retain the lands in grazing use. GRP also supports the restoration and enhancement of grassland, including rangeland, pastureland, shrubland and certain other lands. As of 2008, GRP protected about 43,300 grassland hectares from conversion to crop land using permanent easements, and another 253,000 hectares using 0 – 30 year term contracts.[32]

The carbon sequestration benefits from land enrolled in GRP arise from forestalling or preventing the conversion of grassland to cropland or developed uses. The technical potential for avoided losses of sequestered carbon from preventing conversion of grassland to cropland are estimated to be 0.7 – 4.39 $mtCO_2e\ ha^{-1}yr^{-1}$, with poorly managed grazing lands providing fewer benefits compared to well managed grazing lands (see review of studies in Eagle and Sifleet 2011, Tables 22 and 27). These impacts are greatest for the GRP land that is under permanent easement. Assuming an average estimated GHG benefit of 2.5 $mtCO_2e\ ha^{-1}yr^{-1}$, the approximate impact of the GRP would be .7Tg $CO_2e\ yr^{-1}$, about one-tenth of a percent of net GHG potential for the agricultural and forestry sector (Table 1). The additionality of sequestration on GRP lands is not known, however. Also, leakage could be significant, if the demands for converting grassland to cropland simply shifted to adjacent grassland parcels that are not under contract.

Agricultural ‘working lands’ conservation programs, such as the Environmental Quality Incentive Program (EQIP) and Conservation Stewardship Program (CStP), pay participants to voluntarily adopt or to maintain and enhance conservation practices on farmland that remains in production, including conservation tillage, precision use of fertilizers

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[32] Personal communication with Elizabeth Crane, GRP National Program Manager, USDA-NRCS, August 31, 2010.

and pesticides, and anaerobic digesters on dairy farms. EQIP contracts are 1-10 years in length, and CStP contracts are 5 years. In 2008, of payments totaling $943.4 million, EQIP provided $42.5 million to assist farmers with adopting conservation tillage on 1.1 million hectares, $35.7 million to adopt improved nutrient management on 1.6 million hectares, and $592.4 million to adopt improved livestock practices (Horowitz and Gottlieb 2010, USDA-NRCS 2009). The CStP, authorized by the 2008 Farm Bill to pay participants for conservation actions that enhance conservation performance beyond a stewardship threshold, targets enrollment of about 5.2 million hectares/year at an average cost (for all practices funded) of $44.5/hectare/year. (CStP replaces the similar Conservation Security Program, which funded conservation enhancements over the 2002-2008 period.) A third program is Conservation Technical Assistance, which assists individuals and entities with technical expertise to voluntarily adopt resource conserving practices.

The technical GHG mitigation potential for many activities funded through these programs has been well studied, with no-till estimated to sequester carbon at the rate of between -.26-1.60 $mtCO_2e\ ha^{-1}yr^{-1}$ and improved grazing management at the rate of 0.0 – 2.2 $mtCO_2e\ ha^{-1}yr^{-1}$ (see Table 1, 14, 22 in Eagle et al. 2011, Table 4 in Eagle and Sifleet 2011).[33] Of conservation tillage practices, scientists are most confident that no-till provides positive GHG benefits; significant uncertainty surrounds GHG mitigation potential for other types of conservation tillage. Though also uncertain, reduction of fertilizer N rates has been estimated to potentially mitigate between .05 – 0.79 $tCO_2e\ ha^{-1}yr^{-1}$ (Eagle et al. 2011). NRCS estimates GHG mitigation in 2010 at 3.97 Tg $CO_2e\ yr^{-1}$ through EQIP and less than .01 Tg

[33]Drought conditions have been found to make rangelands become a C source if at least two-thirds of the area is in drought conditions (Zhang et al. 2010).

$CO_2e\ yr^{-1}$ through CStP, primarily from producers adopting wildlife habitat management, prescribed grazing, windbreaks and shelterbreaks (Chambers 2011) (Table 1).

However, the additionality of these working lands programs for mitigating GHG is uncertain. Large livestock operations are subject to pollution regulations, but EQIP funding is made available to help offset producer cost of meeting the regulations. For these producers, GHG mitigation through EQIP-funded practices would not be additional (attributable to EQIP) since the mitigation is attributable to the regulation. Conservation Technical Assistance, which is estimated to provide 8.2 Tg $CO_2e\ yr^{-1}$ in mitigation benefits annually, is provided to producers and entities complying with various environmental regulations as well as to producers who must meet environmental compliance requirements to receive federal commodity support payments. On the other hand, the estimates attributable to these programs only represent mitigation on currently funded contracts, and do not take into account NRCS prior program funding (for now expired contracts) that induced farmers to adopt practices that still provide GHG mitigation benefits.

While the short term nature of EQIP and CStP contracts (maximum of 10 years) suggests GHG mitigation might be further limited, the program payments are intended to offset adoption costs, so the expectation is that farm operators will continue the practice after contract termination. However, we are not aware of any studies that examine practice continuation after EQIP or CSP contract termination, so the permanence of these practices in mitigating GHG is uncertain.

Forestry Conservation Programs

Although about two-thirds of the 271 million hectares of forestland in the U.S. is privately owned, after 2008 only one federal program had forestlands as a main focus of conservation effort. USDA's Forest Service cooperates with states to purchase permanent conservation easements on private forestlands through the Forest Legacy Program (FLP). By January 2012, about .88 million hectares had been protected through the FLP; no estimates are available of the GHG mitigation benefits arising from the FLP. However, many of the agricultural conservation programs mentioned above provide financial assistance to landowners willing to retain land in forestry uses and adopt forestry practices on private forestland. GHG mitigation benefits associated with these activities are included with the respective agricultural programs.

6. *Agriculture and R&D Policy*

Investments in agricultural research and development (R&D) have increased U.S. agricultural productivity dramatically over the past six decades or more.[34] Very little R&D investment is specifically targeted for GHG mitigation, but agricultural productivity gains in the crop sector have influenced patterns of GHG emissions in two ways. First, these gains have increased total factor productivity (TFP), or output per unit of total inputs, which will decrease emissions per unit of output, for constant input shares. Second, increased TFP has been accompanied by changing patterns of input use, with countervailing GHG effects: the intensification of fertilizer, pesticide and irrigation inputs per unit of land has reduced the demand for land and consequently GHG emissions from land conversion, but at the same time increased the rate of GHG emissions from energy-intensive inputs per hectare. Thus, the direction of the effect of productivity-enhancing R&D on emissions is not obvious *a priori*. It rests on the estimates of avoided land-use change due to productivity gains. The land-use change (LUC) dynamics involved in the calculation of the no-productivity counterfactual; the

[34]Statistical studies of the impact of research on productivity have mainly examined the post-World War II period. Total factor productivity in US agriculture has, however, increased since the mid-1930s (Hayami and Ruttan, 1985).

estimates in the literature, which is in the early stages of development, cover a wide range. Using a simple accounting model which in effect assumes an infinitely elastic supply of landsuggests the green revolution resulted in very large scale LUC avoidance (Burney et al., 2010) [hereinafter referred to as "BDL"]. Using this model, BDL estimated a very powerful GHG mitigation effect at low cost. Alternative estimates (Evenson and Rosegrant, 2003; Stevenson et al. 2011) provide much lower estimates of LUC avoided. To this point no careful GHG accounting has been made with these counterfactual estimates to determine both the direction and scale of the GHG mitigation impacts, but it is an important step for future research.

6.1 USDA (and other public and private) Agricultural Research Programs

In 2006, total U.S. public and private sector agricultural research expenditures were more than $11 billion. In real terms, total U.S. agricultural research investment in 2006 was two and a half times greater than it was in 1961. Private agricultural research has tended to grow faster, though with greater variability across years than public expenditures over the period 1961-2005.

The U.S. public system is characterized by a relatively decentralized Federal-state partnership. In 2006, Federal funding of agricultural research was nearly $3 billion, and state funding over $1.3 billion. Of the Federal funding, about $2 billion came through USDA and the rest from other Federal institutions. Private sector funding was just under $6.8 billion in 2006, of which over $700 million was spent by the public sector.

Not all research is oriented towards farm productivity. For example Alston et al. (2010) estimate that from 1975 through 2007, between 57 and 69 percent of all U.S. public agricultural research has implications for farm-level productivity, with the share declining since the mid-1980s. In 2006, 54% of U.S. private sector research, or $3.3 billion, was performed by the food industry, where much research is directed at new product development and very little influences farm productivity. The rest of private sector research is directed at technology development for crop and livestock production, with the largest investments in crop seed and biotechnology, farm machinery, agricultural chemicals, and animal health. For 2006, for example, we estimate just over half of the public-private research total was directly related to farm productivity.

6.2 Input Use, Technological change and U.S. productivity trends

The research-driven technologies most commonly associated with increased crop yields are sometimes described as "Green Revolution" technologies, after the changes associated with the spread of high-yielding varieties of wheat and rice in developing countries, which began during the 1960s. These technologies are associated with increasing crop yields (output per unit of land), through increasing applications of fertilizer and other chemical inputs. Technological change that affects fertilizer use and land use will have implications for GHG emissions. Further, nitrogenous fertilizers represent a double source of emissions, both from the energy used to produce and apply the chemicals, but also from the N_2O emissions from cropland application. In the U.S., total fertilizer peaked in the 1970s, and then fell following the energy price shocks as of the 1970s; starting in the mid-1980s, usage has seen a very slow rate of increase. Since that time, U.S. fertilizer content has continued to substitute away from phosphate and potash, toward nitrogen; as a result, U.S. total nitrogen use has increased at a much faster rate than total fertilizer, although the rate of increase has dramatically declined since 1993. Land in crops decreased in the U.S. by 7 percent from 1959 to 2007.

Crop yields represent a measure of partial factor productivity. A preferred measure of the impacts of agricultural research on productivity is total factor productivity (TFP), which records changes in output per unit of all inputs. TFP is considered a better indicator of technical change than 'partial factor productivity' indicators because it does not include the effects of input substitution; however, it is still imperfect as a measure of innovation (Fuglie et al., 2007). It is important to maintain the distinction between yield growth and TFP growth in order to understand the literature on the impacts of agricultural R&D on "productivity." In our analysis, we rely on the identity "yield growth = TFP growth plus growth in inputs per unit of land" (Fuglie 2008).

TFP in U.S. agriculture grew at an average annual rate of 1.52 percent between 1948 and 2009 (USDA/ERS 2012). Agricultural R&D, in particular public sector R&D, has been a major driver of this TFP growth (Alston et al., 2010; S.L. Wang et al., 2012).

6.3 Assessing the GHG implications of research-driven technological change

In a recent study, Burney et al. (2010) implemented a detailed GHG accounting framework for analyzing the net global effects on GHG emissions of productivity-driven increases in crop yields, and estimating the expenditures on productivity-oriented R&D per ton of emission reduction. Adjusting their results to U.S. circumstances, we provide order-of-magnitude estimates from their study for the U.S. However, the avoided land-use change estimates employed in the calculations may be unrealistically high.

Their approach is to compare GHG outcomes from two counterfactuals with technology (crop yields, fertilizer application rates) frozen at 1961 levels against GHG outcomes with actual ("real-world", RW) technological change (see also Borlaug, 2007). The bounds on the mitigation estimates are established with two alternative-world scenarios: in the first (the upper bound), crop production must be sufficient to sustain the actual growth in standard of living (crop output per person) over the period for the growing population (AW1). Acknowledging that AW1 does not reflect the role in the real world of declining prices associated with productivity increases and consequently would overstate demand, BDL create a second alternative world scenario (AW2) in which crop production must be sufficient to sustain 1961 standards of living for the growing population (their lower bound). Holding crop yields and fertilizer application rates frozen at 1961 levels throughout the 1961-2005 period in AW1 and AW2, the simulation scales up land in crops and fertilizer production sufficiently to achieve these two alternative production levels; the simulation projects that cropland would almost triple between 1961 and 2005 to achieve the actual growth in standard of living (AW1) and would approximately double to maintain the 1961 standard of living for a growing population (AW2).

The global GHG accounting provides estimates of four categories of emissions associated with crop production in the counterfactuals, as well as in RW. These categories are biomass and soil carbon releases from land-use change; methane emissions from rice production; GHG emissions from fertilizer production; and GHG emissions from fertilizer application to cropland.[35] By a wide margin, the dominating factor in the calculations comparing RW against both counterfactuals is the effect of avoiding carbon releases from land use change.

[35] In the AW1counterfactual, livestock populations are assumed to be the same as in the RW, because total food and feed production remain the same, and thus GHG emissions due to enteric fermentation, manure management, and grazing land management are identical in both scenarios. No transportation or fuel is included in the analysis, which represents a conservation assumption (reducing the difference between RW and AW1 [see p. 12056]. In the AW2 counterfactual (which assumes constant per capita production at 1961 levels), livestock numbers are lower in than in the RW, and livestock GHG emissions are consequently lower as well.

For the more conservative counterfactual (AW2), BDL (2010) estimate that the global net effect of higher yields attributable to agricultural R&D during 1961-2005 has been to avoid between 2.4 GtCO_2e per year (1 Gigaton = 1 billion tons), at a cost of $4.0 per mt CO_2e reduced.[36] They conclude that investments in yield improvements compare favorably with other commonly proposed mitigation strategies.

For our downscaling of the BDL estimate of global GHG mitigation attributable to agricultural-R&D to the U.S., we adjust the parameters for the dominating factor, avoided emissions from land use change, where the U.S. differences from the global average substantially affect the total mitigation estimate. Using the same data sources and methods as BDL, we estimate U.S. aggregate yield growth between 1961 and 2005 has been the same as global yield growth. Thus, the estimated U.S. land use change into crop lands to compensate for the lower yield growth from 1961-2005 is comparable to the global rate of increase. However, average carbon stocks in biomass and soils are lower in the temperate zone than in the globe as a whole. Using the BDL approach, we estimate that, on average, avoided land-use-change emissions per hectare of cropland in the U.S. are 76 percent of the global emission rate. To tailor the BDL estimate of global R&D costs per ton of CO_2e mitigation, we estimate that U.S. research expenditures per hectare of cropland (arable plus permanent crops) over the period 1961-2005 were 2.1 times the global average, and maintain conservative assumptions about the share of U.S. agricultural R&D funding from 1961-2005 that was productivity-related, and the contribution share of productivity-enhancing R&D to crop yield growth.

[36]This range of estimates for two counterfactuals (AW1 and AW2, as explained in following text) is based on the assumptions that 34 percent of yield growth is due to R&D and 70 percent of global R&D targets productivity improvements. BDL also report a range of estimates based on the unrealistic assumptions that all yield growth is due to R&D and all R&D is targeted to productivity improvements, in which estimated mitigation attributed to R&D is tripled, at 43 percent higher cost, so on net, cost per ton mitigation is cut in half. We do not calculate U.S. estimates using these assumptions.

For BDL's more conservative counterfactual (AW2), downscaled BDL estimates for the U.S. during 1961-2005, the average rate of GHG mitigation attributable to productivity-related agricultural R&D was on the scale of 205 TgCO_2e per year, at a cost of between $20 per mt CO_2e reduced. Compared to mitigation estimates for the current U.S. policies reported in Table 1, these estimates would suggest R&D has accomplished the greatest amount of mitigation on an annual basis to date.

However, Stevenson et al (2011) provide a far smaller estimate of LUC avoided by the green revolution, 30 M ha rather than 850 M ha in BDL's AW2 scenario. Their conclusion is based on estimates from IFPRI's partial equilibrium IMPACT model (Evenson and Rosegrant 2003) and the general equilibrium GTAP-AEZ (Stevenson et al 2011). Though the GHG emission reductions from avoided land-use change strongly dominate the accounting in BDL, with these counterfactual estimates, careful GHG accounting will need to be done to determine both the direction and scale of the GHG mitigation impacts. This GHG accounting remains to be done. Hence for agricultural R&D, we consider current estimates of past mitigation and cost per ton mitigated to be uncertain.

7. Summary and Perspective

Current agricultural sector programs have achieved substantial GHG mitigation in U.S. agriculture and forestry – despite not having been designed with the goal of GHG mitigation. Recent research has provocatively suggested that, among the current agriculture sector programs we reviewed, productivity-improving R&D in agriculture may have induced the most mitigation in the U.S. on an annual basis (based on analysis over the period 1961-2005). However these estimates of GHG mitigation may be predicated on unrealistically high estimates of LUC. More realistic LUC estimates raise questions not only about the scale but also the direction of the effect. The necessary GHG accounting remains to be done.

The average annual contribution to GHG mitigation over the 1997-2008 period from USDA voluntary agricultural conservation programs offset about 8 percent of average agricultural emissions during the period. These programs, particularly the Conservation Reserve Program (CRP) which subsidizes crop land retirement for 10-15 years, have substantially increased the stock of carbon in agricultural lands over the past few decades – even after taking into account emissions leakage (when crop production on enrolled land is displaced to land outside of the program) and carbon releases when land reverts to cropland following exit from the program. However, current increments to carbon stocks are declining, because the program has been operating at a fairly consistent scale for several decades, and so carbon stocks on enrolled lands are approaching new equilibria associated with their change in land use. In order to maintain - or to increase - the rate of carbon sequestration, the scale of the CRP would need to be increased. Further, proposed cutbacks in conservation programs could actually <u>reverse</u> the past mitigation benefits of the program, if exiting CRP land operators were to return their land to crop production at the same rate as in the past.

Finally, though farm income support programs currently have twice the funding of conservation programs, the impacts of farm income support programs on the scale of crop land use have been mixed, with the weight of the evidence suggesting expansionary impacts are relatively modest.

Substantial additional mitigation potential exists in the sector at relatively low GHG prices. Implementing a broad-based GHG incentive program - such as the proposed federal cap and trade program - has the greatest potential for capturing the potential. In contrast to the conservation programs, program scale is not dependent upon budget, but rather on how tight the GHG emission cap is set, and how many offsets agriculture and forestry are allowed to sell to firms in sectors covered by the emissions cap. Further, among the alternative programs reviewed, this is the only one where a price is established specifically for GHG emissions, through the opportunities to trade allowances or offsets, thereby providing incentives for the market to supply the most cost-effective sources of GHG mitigation.

However, the policy debate is more narrowly focused on promoting renewable energy over the next decades. The current biofuels mandate is projected to achieve substantial annual emission reductions by the time it is fully implemented in 2022 – 3.5 times the average annual emission reduction of conservation programs 1997-2008. However, questions remain about the feasibility of implementation due to technology and infrastructure challenges. The treatment of bioelectricity generation in new proposals promoting renewable or clean energy in electricity generation is uncertain at this point - decisions about how to do the GHG accounting for lifecycle emissions from biomass feedstocks, including agricultural waste, landfill wastes, and dedicated energy crops, are being delegated to expert sources. Estimates from the cap and trade program discussed above (H.R. 2454) suggest that - even with an inclusive treatment of bioelectricity from dedicated energy crops - bioelectricity and reduced on-farm reliance on fossil fuels due to higher energy prices would generate 15 percent of the mitigation potential from the sector over the 2012-2059 period at the GHG prices forecast given the scale of the cap – not counting any gains from the biofuel mandate.

The narrow focus on energy incentives would miss most of the potential sources of agriculture and forestry mitigation, including additional carbon sequestration in biomass and soils, and reduction of emissions from fertilizer application to soils and from livestock. Agricultural conservation programs target many of the agricultural sources of mitigation, including livestock waste management and land management. The largest gap in agricultural and forestry sector coverage is the lack of programs targeting the potential mitigation from afforestation and improved forest management, which represents 75 percent of total mitigation projected for the cap and trade program over the 2012-2059 period.

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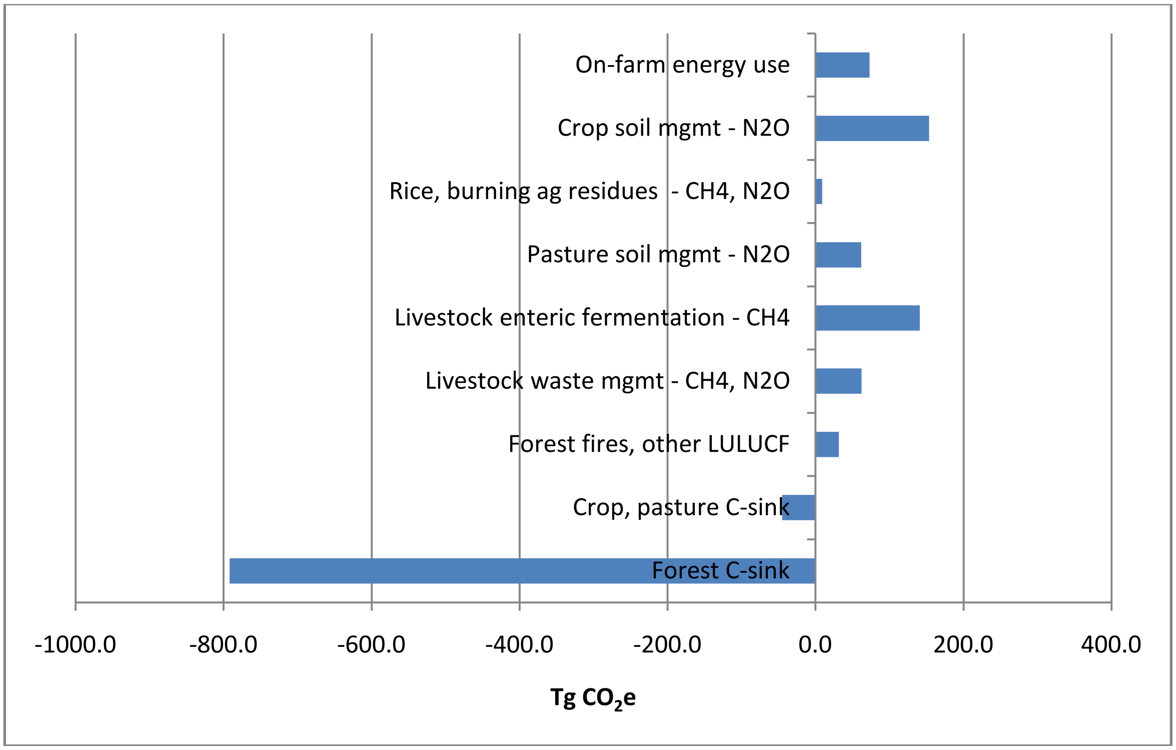

Figure 1.Agriculture and forestry greenhouse gas emissions and sequestration, 2008.
Negative values indicate carbon sequestration. Forest C-sink includes afforestation and forest management. Source: US EPA 2010b, Table 2-8, 2-9, 2-10, 2-14.

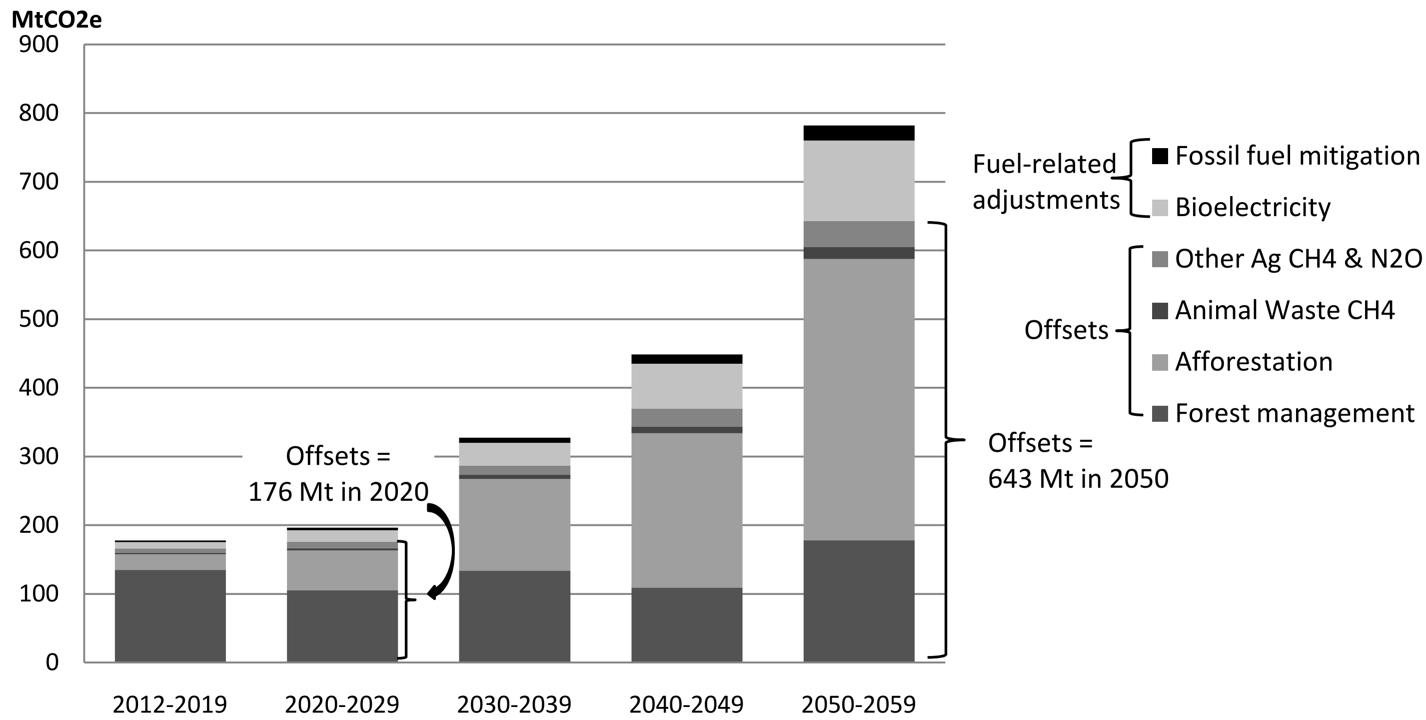

Figure 2. Estimated U.S. agriculture and forestry sector GHG mitigation with American Clean Energy and Security Act of 2009 (H.R. 2454).

Note: In the proposed legislation's offset program, unregulated sectors, including agriculture, could reduce emissions and offer the reductions for sale to regulated firms to "offset" their emission reduction requirements. In addition, the energy sector's cap on allowable emissions would result in higher fossil fuel prices. In response to the higher fuel prices, agriculture could also contribute to emissions reductions by reducing on-farm fuel use and by increasing the supply to the energy sector of agricultural feedstocks to produce bioelectricity.

Source: D

Table 1. Contributions to US GHG mitigation from current or proposed policies

	Period	Estimated annual mitigation, CO_2e (in Tg/yr)	Policy costs or CO_2e price	Notes (assumptions and sources)
Proposed policies:				
H.R. 2454 GHG cap & trade				
Agriculture offsets	2020-29	12	Allowance/ offset price = \$14.25/t CO_2e	Mitigation from policies currently in place is included in the reference case (with no cap-and-trade). Assumes full GHG pricing for ag and forestry (effectively a mandatory program); allowance price increases 5% per year over the period. Source: US EPA 2009.
Forestry offsets *	2020-29	163		
Fossil fuel energy use (ag&f)	2020-29	4		
Bioelectricity (ag feedstocks)	2020-29	17		
Total	2020-29	196		
Agriculture offsets	2050-59	55	Allowance/ offset price = \$61.60/t CO_2e	* Latta et al (2011) model a voluntary forestry program.
				They project mitigation, relative to US EPA 2009, to be:
Forestry offsets *	2050-59	588		At \$5/t, 1/3 of afforestation, 1/6 of forest management; at \$15/t, ~ 1/3 each of afforestation,
Fossil fuel energy use (ag&f)	2050-59	22		forest management; and at \$30/t, ~ 40% each of afforestation, forest management.
Bioelectricity (ag feedstocks)	2050-59	117		They assume constant allowance prices over time, so the results are not directly comparable
Total	2050-59	782		to results in US EPA 2009.
Clean Energy Standard (Bingaman proposal)	2025	**	Credit price = \$.033/kWh, electricity price + \$.097/kWh	** Comparable to bioelectricity mitigation for HR 2454 GHG cap and trade policy, based on a comparison of changes in levels of electricity generated by fossil-fuel and bioelectricity sources. Estimates of changes in GHG emissions are not comparable, because EIA only considered emissions from generation (assigning 0 emissions to renewables, nuclear). Source: US EIA 2011c.
	2035	**	Credit price = \$.080/kWh, electricity price= \$.113/kWh	

Table 1. Contributions to US GHG mitigation from current or proposed policies

	Period	Estimated annual mitigation, CO_2e (in Tg/yr)	Policy costs or CO_2e price	Notes (assumptions and sources)
	Period	**Estimated annual mitigation, CO_2e (in Tg/yr)**	**Policy costs or CO_2e price**	**Notes (assumptions and sources)**
Past/current policies:				
Renewable Fuel Standard (RFS2)	2022	138	Costs borne privately;	When full mandate blending level has been achieved.
			no direct policy costs	Source: US EPA 2010a.
Conservation Programs				
Conservation Reserve Program				
Grassland soil	1997-08	16	USDA spent $1.8B on	Sources: Grassland soil: USDA, 2011, p. 61; afforestation: Data Appendix, USDA FSA 2008;
Reduced fuel and fertilizer	1997-08	9	CRP contracts in 2008	reduced fuel and fertilizer: USDA-FSA (2008).
Afforestation	1999-09	15	($125.40/ha). #	# Does not take into account on-farm savings from reduced fuel/fertilizer and other impacts
Wetlands	1997-08	no consensus		on net farm income from CRP enrollment.
Total		~39		
Wetlands Reserve Program				
Wetland restoration		no consensus		The direction of net GHG impacts varies by soil type, past uses and wetland types
Grassland Reserve Program				
Prevented conversions to cropland		0.7		Does not consider whether benefits are additional or if leakage reduces the benefits
Working Lands Programs - EQIP, CStP				
Conservation tillage (no-till)		-0.29 - 1.76		Based on sequestration of -.26-1.60 mtCO2e ha-1yr-1 (Eagle and Sifleet 2011) and 1.1 million ha receiving EQIP payments for conservation tillage in 2008. Does not consider whether benefits are permanent, additional or if leakage reduces the benefits
Improved grazing management		NA		
Public and private R&D		uncertain		