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Achieving the Mid-Century Strategy Goals for Deep Decarbonization in Agriculture and Forestry

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Review
This working paper has not undergone a formal review process, but has been reviewed by some experts in the field. It is intended to stimulate discussion and inform debate on emerging issues.

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Summary

The U.S. Mid-Century Strategy for Deep Decarbonization (MCS), released in November 2016, calls for the United States to reduce economy-wide greenhouse gas (GHG) emissions by 80% by 2050. A significant portion of those reductions are to come from the forestry and agricultural sectors. Those reductions will be more difficult and more expensive to achieve if the current U.S. forest sink is not maintained and the GHG impacts of agriculture are not addressed.

This working paper seeks to address those two tasks, first, by presenting a cost distribution of various climate smart agricultural and forestry practices and an analysis of the geographic distribution of such activities in the United States, and second, by doing what the MCS does not: offering policy recommendations to achieve deep GHG reductions.

To finance climate-smart practices on working lands, a national carbon bank is proposed. The bank would be designed to provide carbon price certainty to agricultural and forest landowners while assuring that climate-smart practices provide real GHG gains. Other recommendations include investing in technical assistance for farm, ranch, and forest producers; facilitating market-based approaches such as labeling products produced using climate-smart practices; encouraging such practices through federal crop insurance subsidies; encouraging forest restoration and conservation; and promoting broader use of solid wood products.

EXECUTIVE SUMMARY

The U.S. Mid-Century Strategy for Deep Decarbonization (MCS), released in November 2016, calls for the United States to reduce economy-wide greenhouse gas (GHG) emissions by 80% by 2050 (The White House 2016). A significant portion of those reductions are to come from the forestry and agricultural sectors (collectively referred to here as the land sector). The MCS calls for a reduction in net land sector emissions through a combination of direct emissions reductions and an expansion in the land sector carbon sink (or "land sink") through increased carbon sequestration in trees, other biomass, and soils.

This paper seeks to provide a roadmap for the United States to achieve the goals set out in the MCS for carbon sequestration and greenhouse gas (GHG) emissions reductions in the land sector. It describes a range of practices in the agricultural and forestry sectors that may contribute to the land sector goals in the MCS, along with the estimated GHG mitigation potential associated with each practice. It then presents a price distribution analysis of selected practices, which relates the mitigation potential to the carbon price at which the practice becomes economically feasible to implement. This analysis illustrates the magnitude of financial incentives that might be necessary to produce the GHG mitigation results envisioned in the MCS and allows for comparison of the cost-effectiveness of different agricultural and forestry practices. The price distribution analysis is followed by a geospatial analysis of the geographic distribution of mitigation potential, which provides valuable insights into the regional allocation of agricultural and forestry incentives needed to achieve MCS goals. The geographic analysis may also be useful in building support for policies to support the MCS goals among regionally diverse stakeholders, given that the analysis shows that every region of the country can benefit from incentives for GHG mitigation in the land sector. Finally, the paper details a series of policy recommendations that, if enacted, can help put the United States on a pathway to meeting its MCS land use goals.

Background

The MCS called for the United States to reduce economy-wide GHG emissions by 80% by 2050. Carbon sequestration and GHG emissions reductions from the land sector factored heavily into the pathway that the MCS laid out to achieve that goal. However, the MCS stopped short of detailing the types of policies and programs that would be necessary at the federal and state levels to achieve its economy-wide and sector-specific GHG reduction goals. This paper aims to fill those gaps by bringing analyses of the mitigation potential from climate-smart land use practices to bear on MCS goals and by placing the MCS in the context of the current policy landscape for conservation in agriculture and forestry. Economic, geographic, and policy analyses inform recommendations for expansion of existing policy approaches and new policy innovations that will promote additional mitigation opportunities in agriculture and forestry in line with the MCS goals. Land use practices addressed through these policy recommendations include crop management practices such as nitrogen fertilizer management, conversion to no-till farming, and methane management from rice paddies; livestock management practices such as manure management, methane reductions from enteric fermentation, and grazing practices; and forestry practices such as reforestation, afforestation, improved forest management, and avoided conversion.

Price Distribution of Mitigation Potential

Under its Benchmark scenario, the MCS calls for the stabilization of annual land sector sequestration at approximately 650 million metric tons of carbon dioxide equivalent (MMT CO_2e) by 2050, whereas the most ambitious scenario calls for an expansion of land sector sequestration to approximately 900 MMT CO_2e per year by 2050.

This analysis suggests that this goal may be achieved at a carbon price of \$10/tCO_2e through a combination of forest expansion, improved forest management, and livestock manure management strategies, provided that the existing carbon sink does not continue to degrade. Additional emissions reductions may be required to offset losses in net emissions if the current downward trend in land sector sequestration continues unabated. However, some practices not included in the price distribution analysis due to data limitations may also contribute significant mitigation potential.

Geography of Mitigation Potential

There are distinct regional trends in the concentration of mitigation potential from the range of land use practices examined here. Climate-smart forestry practices show greater potential along the Pacific and Atlantic coasts, in the Rocky Mountains, throughout the Southeast, and in the northern halves of the lake states. Interventions on public forestlands would be concentrated in the western United States, where a higher proportion of forests are publicly owned; mitigation potential from private forestlands is greatest through the Southeast and Northeastern states as well as in the northern parts of the lake states.

Potential for achieving reduction through agricultural practices, meanwhile, dominates much of the central United States, including the Corn Belt and southern portions of the lake states. Mitigation potential from increasing soil carbon in pastureland and reducing nitrogen fertilizer use is spread throughout the Central Plains, stretching from the Dakotas and Montana in the north to Texas in the south. The Central Valley of California shows high potential for reducing fertilizer emissions as well, as does North Carolina, which also holds opportunities for livestock manure management.

Policy Recommendations

The recommendations outlined below seek to put the U.S. land sector on a path toward achieving the MCS goal for GHG mitigation through a combination of new policies and adaptations to or expansions of existing government programs. One important implication of these recommendations and of this paper more broadly is that the federal government will need to increase, dramatically in some cases, available financial resources for policies that promote climate-smart agriculture and forestry. Meeting the goals of the MCS requires it.

National Carbon Bank

Housed within the U.S. Department of Agriculture (USDA) and operating as a retail carbon offset broker, a national carbon bank could significantly scale up the adoption of climate-smart agricultural and forestry practices by creating an effective price floor for land sector carbon offsets, while ensuring stable demand for offsets through the use of reverse auctions or other financial mechanisms. The bank could also ensure the environmental integrity of traded offsets through the use of self-insurance mechanisms such as an offset buffer pool.

Technical Assistance

The USDA should bolster existing technical assistance efforts through more targeted landowner outreach and increased capacity for hands-on individual consultation services. Capacity for targeted technical assistance can be strengthened through innovative grants to state agencies, private sector partnerships, and improved metrics on services offered to farmers and forest owners.

Climate Labeling

In partnership with stakeholders, the USDA should encourage the development of voluntary consensus standards that specify best practices for reducing GHG emissions and limiting environmental harms throughout the agricultural supply chain. Such standards could be used to drive demand for climate-smart products among consumers and as a means of verifying the marketing claims of food and beverage companies.

Crop Insurance

USDA's Risk Management Agency should explore the possibility of leveraging crop insurance premium subsidies for farmers and practitioners who adopt climate-smart cropping practices. This initiative will require an expansion of data collection on the link between climate-smart practices and crop yields.

Forest Resilience on Public Lands

With more funds now securely dedicated to forest management as a result of the U.S. Forest Service budget reform enacted in the 2018 Omnibus Spending Package, the Forest Service should establish a designated fund for forest resilience to proactively manage the risk of future wildfires while preserving carbon stocks on National Forest lands.

Incentives for Private Forest Management and Restoration

Supplying more financial and technical assistance resources for the Environmental Quality Incentive Program (EQIP) can help provide the necessary resources to family forest owners who manage a significant proportion of U.S. forests but who have historically received insufficient support from the USDA through cost-share and incentive programs. New incentive programs can also target carbon sequestration gains from improved management of commercial and industrial forests.

Forest Legacy Program Expansion

Building on the success of the Forest Legacy Program (FLP) in protecting working forests through cost-sharing conservation easements or transition to public ownership, Congress should expand the carbon sequestration benefits of

FLP by creating a pilot FLP-carbon program that would prioritize conservation of forestlands with the greatest carbon benefits. This program would use additional resources, leaving the existing FLP intact.

Reforesting Marginal Pastureland

The USDA should prioritize the reforestation of marginal pasturelands by making these lands eligible for the Conservation Reserve Program (CRP), which has already realized significant carbon sequestration benefits from restoration of marginal croplands.

Expanding Markets for Wood Products

Public investments to promote market growth of wood construction materials like cross-laminated timber (CLT) can scale up demand for forest products, thereby providing additional incentives to retain and expand forest land. Opportunities exist at all levels of government to promote wood markets through innovation grants, building competitions, architect and engineer training programs, and policy reforms to ensure fair market competition.

MID-CENTURY STRATEGY FOR DEEP DECARBONIZATION

Mid-Century Strategy Framework

Released during the last year of the Obama administration in 2016, the U.S. Mid-Century Strategy for Deep Decarbonization outlined ambitious goals to reduce economy-wide U.S. GHG emissions by 80% by 2050 as part of the country's commitments to the Paris Agreement. The MCS emphasized the role that U.S. lands, including forests and agricultural land, should play in achieving these goals. This emphasis on the potential of agriculture and forests to address climate change is critical in light of the changing emissions profile of the U.S. land sector.

Over the last several decades, U.S. lands have sequestered more carbon in plant biomass and soils than has been emitted; the "land sink" offsets more than 11% of economy-wide GHG emissions in 2014 (The White House 2016). However, accelerating urbanization, more intense droughts and wildfires, and poor forest management practices, combined with aging forests, threaten to diminish the capacity for U.S. lands to capture and store carbon. Meanwhile, agriculture now accounts for 9% of economy-wide GHG emissions in the United States, due in large part to GHG emissions from soil management and livestock (U.S. EPA 2018).

Without improved conservation and mitigation practices in forests and agriculture, the United States is at significant risk of failing to meet its climate goals. As noted in the MCS, the most important strategies to promote mitigation of GHG emissions in forests and agriculture include forest conservation and expansion, carbon sequestration in soils, wetland conservation, and the reduction of nitrous oxide and methane emissions in agriculture. In line with these strategies, the MCS calls for an expansion of 40 million to 50 million acres of forests over the next 20 to 35 years, enhanced soil management and improved soil health for cropland and grassland soils, and development of emissions reduction technology for livestock and crop management (The White House 2016).

By comprehensively addressing forests and agriculture through the lens of GHG mitigation, the United States has an opportunity to simultaneously sequester carbon in trees and soils, reduce GHG emissions from agricultural practices, and generate other co-benefits such as improved air and water quality, healthier ecosystems, enhanced wildlife habitat, greater protection from floods and fires, and a more resilient food system.

Turning the MCS into Tangible Policies

Public policy will be key to achieving the MCS goals in forests and agriculture. The MCS recognized that new and strengthened government policies are needed to increase public and private investment in effective practices, to coordinate state and federal efforts, and to create financial incentives for GHG mitigation strategies among individual forest owners, farmers, and ranchers. However, the MCS stopped short of detailing exactly what policies and programs would be needed at the federal and state level to reach U.S. national climate goals.

Our report aims to fill those gaps by (1) identifying current challenges in existing federal forest and agriculture programs, (2) analyzing the cost-effectiveness of different strategies and their potential benefit in GHG reductions, (3) highlighting where geographically those cost-effective strategies and investments can be made, and (4) recommending policy mechanisms to accelerate the participation of forest landowners, farmers, ranchers, and private sector actors in climate-smart land use practices.

There are several challenges to scaling up the practices needed to achieve the MCS goals. First, current carbon prices in existing carbon offset markets are far too low to create a financial incentive for many farmers and landowners to participate. Low carbon prices combined with high transaction and certification costs prevent many landowners from accessing those markets and receiving revenue for carbon sequestration efforts. Second, portions of the environmental community remain skeptical about carbon offsets as a tool to advance atmospheric GHG emissions. In particular, some environmental advocates continue to raise concerns about permanence and additionality—that is, whether long-term sequestration of land-based carbon can be ensured and whether such sequestration is truly additional to the sequestration would have occurred in the absence of efforts to encourage climate-smart practices in agriculture and forestry. Third, there is a need to provide farmers and landowners with better information about the benefits and costs of adopting climate-smart practices as well as a need for improved tracking of these practices along private sector supply chains in order to build awareness of the desirability of these practices among potential participants.

Policy recommendations must acknowledge and respond to these challenges from stakeholders in order to succeed politically and environmentally.

Examining the Potential for Sequestration in Agriculture and Forests

Our policy recommendations are informed by two types of analysis: (1) a price distribution of the cost and GHG mitigation potential of selected practices and (2) a geographic distribution of mitigation potential and opportunities for implementing sequestration and mitigation practices across the country.

The price distribution charts the potential emissions reductions and carbon sequestration available at a range of $0 to $50 per metric ton of carbon dioxide equivalent (tCO_2e). This chart can help policy makers target interventions to the most cost-effective practices. Data on carbon potential and cost of reductions is derived from estimates in published literature.

The geospatial analysis of mitigation potential identifies areas of the United States to target with policies and incentives for various carbon sequestration and GHG emissions reduction practices. This analysis, which includes mitigation potential maps for forestry and agriculture practices both individually and together, can help policy makers and stakeholders identify the most promising practices to pursue in their region, thereby allowing strategies and investments recommended here to be targeted accordingly.

Policies Needed to Achieve the MCS

Achieving the MCS goals will require significant public and private investment in agriculture and forest practices, forward-thinking public policies, and collaboration across sectors. Policy recommendations in this paper focus both on enhancing results from existing government programs that already invite investment from agricultural producers, forest owners, and the private sector and on strengthening the foundation of climate-smart policies that could be implemented in the future.

Implementing our recommendations will require a dramatic increase in federal investment; the United States simply cannot move the needle on reducing GHG emissions through land use practices without the financial support of the government. A carbon tax could generate significant revenues that could be targeted to encouraging adoption of climate-smart agricultural and forestry practices. Even in the absence of such a dedicated flow of financial resources, however, government investment will be needed to spur adoption of such practices and to support the infrastructure of people and expertise needed to implement these efforts. Federal investment is needed to help expand and enhance current programs, support the creation of new and innovative programs, develop the capacity for improved technical assistance, and leverage the resources and commitment of the private sector.

This paper's recommendations would also require coordination of various stakeholders. Although the recommendations target existing government programs administered by the U.S. Department of Agriculture, it must be acknowledged that many public and private groups are invested in agriculture and forestry practices. The recommendations to strengthen the coordination among government agencies, environmental nonprofit organizations, producer associations, private companies and foundations, farmers, forest owners, and ranchers across the country. Because concerns can vary among stakeholder groups, the implications of the recommendations for each group are discussed below when relevant.

This paper outlines policy recommendations for agricultural practices, for forestry practices, and for both. Crosscutting recommendations have the potential to scale the impact and adoption of both agricultural and forestry practices. Most of the recommendations fall under the authority of Congress to enact, either through the Farm Bill or stand-alone legislation. If needed, yet other authorities are noted in the recommendation.

PRACTICES CONSIDERED

This paper considers the following climate-smart agricultural and forestry practices:

- Nitrous oxide emission reductions from cropland and livestock
- Improved rice cultivation
- Soil carbon sequestration on croplands and grasslands
- Reduced methane emissions from livestock
- Avoided conversion of forests
- Afforestation and reforestation
- Improved forest management
- Promotion of wood products.

These practices do not reflect all practices outlined in the MCS. Instead, they reflect practices that research and analysis showed were most cost-effective or scalable enough to achieve the MCS goals. Other practices were excluded from consideration due to lack of data.

One important issue discussed in the MCS that was purposefully excluded from consideration in this paper is energy from biomass. The mitigation potential associated with biomass or biofuels was not examined because of the technical and political complexity of bioenergy. Because bioenergy is an important consideration in developing any GHG mitigation plan for the land sector, it deserves a fuller examination elsewhere.

Nitrous Oxide Emission Reductions from Cropland and Livestock

Mitigating nitrous oxide (N_2O) emissions from agriculture through improved management practices for fertilizer and livestock waste is critical to achieving the MCS goals. Nitrous oxide emissions from direct and indirect agricultural sources accounted for 301.8 million metric tons of carbon dioxide equivalent (MMT CO_2e) in 2015 (U.S. EPA 2018). This amount is equal to approximately one-fourth of U.S. non-CO_2 GHG emissions. Although improved waste management and dietary feed has medium potential to mitigate N_2O emissions, improved nitrogen fertilizer practices hold the most potential for immediate mitigation (Galik, Murray, and Parish 2017). In addition to reducing atmospheric N_2O emissions, improved fertilizer management produces co-benefits such as improved water and air quality and reduced input costs for farmers.

Improved Rice Cultivation

Although rice production is a small percentage of U.S. agriculture, significant GHG mitigation potential exists through improved water management, improved rice varieties, and replacement crops (Eagle et al. 2012). Low costs, concentrated geography and high mitigation impact, and co-benefits make mitigation efforts in rice production a feasible opportunity to reduce GHG emissions. U.S. farmers harvested approximately 2.69 million acres of rice in 2015, and the U.S. Environmental Protection Agency (EPA) estimates the U.S. rice sector produced methane emissions of 13.7 MMT CO_2e in 2016 (U.S. EPA 2018). Researchers conclude that rice mitigation practices likely have low to medium potential to reduce overall emissions levels (Horwath 2013). Although the national impact is unknown, a study from California concluded that rice management mitigation practices could reduce GHG emissions by 2.52 metric tons of CO_2e (tCO_2e) per acre (Horwath 2013).

Soil Carbon Sequestration on Croplands and Grasslands

Though agriculture is currently a net source of emissions, the EPA reported that 9.9 MMT CO_2e were sequestered in cropland, and 1.6 MMT CO_2e were sequestered in grasslands in 2016 (U.S. EPA 2018). Murray et al. (2005) characterize the mitigation potential from agricultural soil carbon sequestration to be lower than that available through forestry interventions, but higher than that available through other agricultural interventions. Adoption of practices that promote enhanced carbon uptake on agricultural soils can generate significant sequestration in the near to middle term, but sequestration potential can decline as agricultural soils reach a point of carbon saturation and as some sequestered carbon is re-released into the atmosphere.

Reduced Methane Emissions from Livestock

Methane emissions from enteric fermentation and livestock manure comprise a significant share of GHG emissions from the agricultural sector; they were estimated at 237.8 MMT CO_2e/year in 2016 (U.S. EPA 2018). The MCS does not list a specific emissions reduction goal for methane; instead, it shows methane from agriculture growing as a percentage of total non-CO_2 GHG from 17% to 25% as a result of growth in food production in the United States (The White House 2016). The USDA has estimated that non-CO_2 emissions from agriculture can be reduced by at least 25% from current levels by 2050 through expansion of existing mitigation practices, widespread deployment of recent technological innovations, and expansion of outreach and technical assistance efforts (The White House 2016). However, this projection includes reductions in nitrous oxides, which account for the majority of reductions. A USDA program focused on livestock partnerships is targeting methane emissions reductions of 21.2 MMT CO_2e per year by 2025 (USDA 2016). Galik, Murray, and Parish (2017) estimated the mitigation potential from manure management achievable at various price points.

Avoided conversion of forests

It is essential to avoid conversion of forest land to other non-forested land uses such as urban development and agriculture, which are associated with reduced carbon sequestration and greater emissions from releases of carbon stored in soil and biomass. The MCS projects that avoiding the conversion of 13 million acres of forest land to more developed land uses, compared to a future scenario with higher rates of development, could result in 40 MMT CO_2e of additional sequestration compared to the higher development scenario by 2050. Murray et al. (2005) quantify the rate of carbon sequestration from avoided conversion at 83.7-172.1 tCO_2e per acre per year.

Afforestation and Reforestation

The potential sequestration from afforestation and reforestation (collectively called forest expansion) is significant, but any projects will have to confront challenges around land use conflict and the long time horizon for realizing benefits. Research indicates a potential range from 2.2–9.5 tCO_2e per acre per year for afforestation and 1.1–7.7 tCO_2e per acre per year for reforestation activities, calculated over a 120-year period (Birdsey 1996). Actual sequestration will be influenced by factors like tree species, climate, soil type, management, and other site-specific characteristics (Murray et al. 2005). These rates also depend on the acreage of forest expansion and the age composition of the forest. The MCS calls for forest expansion on 40 million to 50 million acres of land in order to meet the MCS Benchmark scenario by 2050. This expansion would equate to a rate of roughly 2.7 million acres planted annually from now to 2035 (more than double the rate of forest expansion from 1987 to 2012). Because reaching maximum carbon sequestration rates in forests takes time—sometimes decades—reforestation efforts should be initiated as soon as possible (The White House 2016).

Improved Forest Management

Incremental carbon sequestration in the forestry sector from management practices (collectively known as improved forest management or IFM) result in higher rates of sequestration when compared to a baseline or common practice level. IFM can be applied to working or conserved forestlands but requires active management in all cases. Research suggests that the rate of carbon sequestration resulting from forest management practices in the United States is in the range of 2.1–3.1 tCO_2e per acre per year, with variation based on the specific practices, tree species, climate, topography, and soil type (Row 1996). However, the scale of available opportunities for IFM, and the incentive level at which those opportunities become economically feasible, is the subject of debate (Van Winkle 2017).

Promotion of Wood Products

Wood products contribute to GHG mitigation in the forestry sector by storing carbon from harvested trees in long-lasting solid wood products and by providing an economic incentive for the retention and expansion of working forests. Strong markets for wood products are necessary, however, to realize these benefits at scale. This is particularly the case given the MCS's call for significant forest expansion. In the absence of expanded markets, prices for timber would fall under high rates of new forest establishment, underlining the need for strengthening markets for wood. The primary barriers to expanding and developing new markets for wood products include strong competition from other material sectors and a lack of expertise and information on the use of new wood technologies, such as cross-laminated timber, among manufacturers and end users, such as architects and the construction industry. If wood were a more valued resource in construction, there would be greater incentives to protect working forests to maintain the supply of wood products. Further, by reducing the construction industry's dependence on steel and concrete as building materials, the GHG emissions from these sectors could decrease, magnifying the GHG benefit of wood products (WoodWorks n.d.).

PRICE DISTRIBUTION OF MITIGATION POTENTIAL

In 2016, U.S. gross GHG emissions were 6,511.3 MMT CO_2e (U.S. EPA 2018). U.S. forests and agricultural lands sequestered a net 754.9 MMT CO_2e in the same year, offsetting 11.6% of economy-wide GHG emissions (Table 1).[1] The MCS calls for preservation and enhancement of the U.S. carbon sink as well as for a reduction in non-CO_2 GHG emitted from the land sector. Achieving the MCS goals will require interventions targeted to avoiding degradation in the land sink over time and to enhancing mitigation and sequestration through practices such as forest expansion, improved forest management, agricultural emissions reductions, and soil carbon sequestration.

Total carbon sequestration in U.S. lands declined by nearly 10% between 1990 and 2016 (U.S. EPA 2018). Carbon sequestered in agricultural soils has exhibited a strong downward trend, from 40.9 MMT CO_2e in 1990 to just 9.9 MMT CO_2e in 2016, while carbon sequestered in forests declined slightly from 789.7 MMT CO_2e to 745.5 MMT CO_2e in the same period. Without government intervention, this downward trend in net sequestration may be expected to continue as land is converted from forests to cropland and human settlements and as natural disturbances from fire become more frequent due to climate change. Gross agricultural emissions have also risen by 15%, from 489.2 to 562.5 MMT CO_2e, between 1990 and 2016 (U.S. EPA 2018).

Under its Benchmark scenario, the MCS calls for the stabilization of land sector sequestration at approximately 650 MMT CO_2e per year by 2050, accompanied by large-scale deployment of negative emissions technologies. A No CO_2 Removal Technologies scenario assumes that negative emissions technologies will not be available, resulting in increased reliance on the land sink to offset emissions from other sectors. The No CO_2 Removal Technologies scenario calls for an expansion of land sector sequestration to approximately 900 MMT CO_2e annually by 2050. This expansion represents an additional sequestration of approximately 150 MMT CO_2e over a 2014 baseline.

[1] Sequestration is reported in this case as the Net Land Sector Sequestration from Table 1 and is consistent with EPA's figure for LULUCF Carbon Stock Change in 2016 (in U.S. EPA 2018).

Table 1. Agriculture and forestry emissions and sequestration in 2016

Sources of land Sector Emissions and Sequestration		
Agriculture		
Source	**Gas**	**Quantity (MMT CO_2e)**
Agricultural soil management	N_2O	283.6
Enteric fermentation	CH_4	170.1
Manure management	CH_4, N_2O	85.9
Land converted to cropland	CO_2	23.8
Land converted to grassland	CO_2	22
Rice cultivation	CH_4	13.7
Urea fertilization	CO_2	5.1
Liming	CO_2	3.9
Grassland carbon sequestration	CO_2	-1.6
Cropland carbon sequestration	CO_2	-9.9
Total		**596.6**
Forestry		
Source	**Gas**	**Quantity (MMT CO_2e)**
Land converted to settlements	CO_2	68
Forest fires	CH_4, N_2O	30.7
Reforestation/afforestation	CO_2	-75
Urban forest and soil sequestration	CO_2	-103.7
Existing forest carbon sequestration	CO_2	-670.5
Total		**-750.5**
Other land use changes		
Source	**Gas**	**Quantity (MMT CO_2e)**
Wetland emissions	CH_4, N_2O	3.7
Wetland carbon sequestration	CO_2	-7.9
Total		**-4.2**
Total land sector emissions[a]		**710.5**
Total land sector sequestration[b]		**-868.6**
Net land sector sequestration[c]		**-754.8**
Net land sector total[d]		**-158.1**

Source: U.S. EPA (2018).

[a] Total Land Sector Emissions is calculated as the sum of emissions from all activities with positive gross emissions in Table 1.

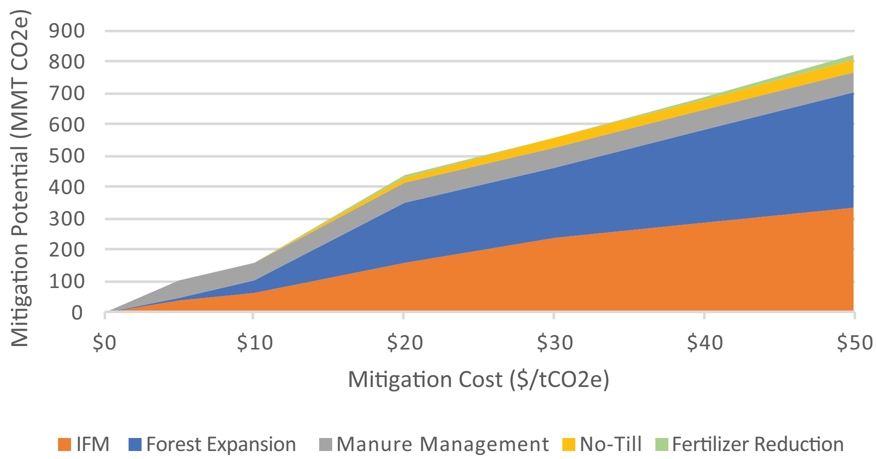
[b] Total Land Sector Sequestration is calculated as the sum of emissions from all activities with negative gross emissions in Table 1.

[c] Net Land Sector Sequestration is calculated as the sum of Land Converted to Cropland, Land Converted to Grassland, Grassland Carbon Sequestration, Cropland Carbon Sequestration, Land Converted to Settlements, Reforestation/Afforestation, Urban Forest & Soil Sequestration, Existing Forest Sequestration, and Wetland Carbon Sequestration.

[d] Net Land Sector Total is calculated as the difference between Total Land Sector Emissions and Total Land Sector Sequestration.

To determine opportunities for expansion of the current land sink, this analysis synthesized existing estimates in the literature of the potential emissions reductions and sequestration available from agricultural and forestry practices at different prices, resulting in an estimated price distribution of mitigation potential in these sectors (Figure 1).

Figure 1. Mitigation and sequestration price distribution for forestry and agriculture



At a price of \$50/tCO_2e, the analysis suggests that 800 MMT CO_2e of additional annual mitigation may be available in the forestry and agricultural sectors. The MCS scenario with the highest land sector sequestration target would require an increase of 150 MMT CO_2e over a 2014 baseline. The price distribution analysis suggests that this goal may be achieved at a carbon price of \$10/tCO_2e through a combination of forest expansion, improved forest management, and livestock manure management strategies, provided that the existing carbon sink does not continue to degrade over time. Additional emissions reductions may be required to offset losses in net emissions if the downward trend in land sector sequestration continues unabated.

The price distribution suggests that forestry mitigation potential increases steadily with higher mitigation prices, while agricultural mitigation potential from included practices appears to plateau near \$20/tCO_2e. Some agricultural practices, such as nitrogen fertilizer management, however, may only be viable at scale at prices higher than \$50/tCO_2e (Pape et al. 2016). In addition, some mitigation practices discussed in this paper are not included in the price distribution due to insufficient data or to avoid the risk of double-counting mitigation potential between conflicting or mutually exclusive practices, though these practices may also contribute additional mitigation potential in the range of prices shown above.

Some of the potential captured in the above price distribution may already be under development. For example, during the Obama administration, the USDA committed to reduce net emissions and enhance carbon sequestration by 120 MMT CO_2e by 2025 through existing programs such as National Resources Conservation Service conservation programs, the Conservation Reserve Program, the Forest Legacy Program, and the Rural Energy for America Program (USDA 2016). However, nearly half of these emissions reductions are projected to occur in the energy sector, rather than in the land sector, and they would not count toward the 150 MMT CO_2e reduction called for in the MCS's No CO_2 Removal Technologies scenario.[2] In addition, there is no guarantee that the USDA will continue to prioritize the achievement of emissions reductions under the Trump administration.

[2] Of the 120 MMT CO_2e of emissions reductions projected by the USDA to occur annually by 2025, 60.2 MMT CO_2e are expected to occur through energy efficiency and renewable generation programs such as the Energy Efficiency and Conservation Loan Program, the High Energy Cost Grant Program, and the National On-Farm Energy Initiative (USDA 2016).

Pricing and Potential for Other Practices

Reliable data on mitigation potential and costs were not available for all relevant interventions. As a result, several practices with potentially high mitigation impacts were not included in the price distribution analysis. Some of these practices deserve further mention below.

Avoided Conversion

Avoided conversion of forests is not included in the price distribution of mitigation due to insufficient data on its mitigation potential. Only two studies in the literature estimated the mitigation potential for avoided conversion, with a range of 5–33.5 MMT CO_2e projected at a price of \$50/tCO_2e (Nabuurs et al. 2007; Alig et al. 2010).

According to the U.S. Forest Service, 57 million acres of forest land could be subjected to significant increases in housing density by 2030 (Stein 2009). Assuming that forest loss would occur on half of that acreage (28.5 million acres) in a business-as-usual scenario, incentives for forest retention could feasibly avoid the conversion of half of that area (14.75 million acres). Excluding potential from avoided conversion of forests to agriculture, these incentives could result in 8.4 MMT CO_2e of annual mitigation potential from avoided conversion. This value is conservative, however, in that it includes only the additional carbon sequestration potential from avoided conversion and not the avoided GHG emissions. It also uses a national average rate of carbon sequestration on forest land, though sequestration rates are generally higher in the southern and eastern United States, which are also the regions with the most potential for avoided conversion.[3]

Mitigation prices for avoided conversion can be approximated using payment rates in the Forest Legacy Program, which protects working forest land from conversion to non-forested land uses. Payment rates averaged \$49/tCO_2e in the eastern United States and \$102/tCO_2e in the western United States, though significant regional variation exists on a more granular level (Table 2).[4]

Table 2. Regional cost of carbon sequestration via avoided conversion and acreages enrolled in the Forest Legacy Program

Region	FLP sequestration Cost (\$/tCO_2e)	Acreage enrolled in FLP
Corn Belt	\$54.77	19,943
Lake States	\$66.73	418,241
Northeast	\$44.62	1,262,820
South Central	\$32.42	125,315
Southeast	\$61.00	159,907
Pacific Northwest	\$191.47	72,492
Rocky Mountains	\$77.92	433,716
Southwest	\$33.61	111,382

Enteric Fermentation

Enteric fermentation refers to the process by which ruminant animals, such as cows and goats, digest cellulose with the aid of gut-dwelling bacteria. This process releases methane as a byproduct. Enteric fermentation was the largest source of land-sector methane emissions in 2016 at 170 MMT CO_2e. The large amount of methane produced by U.S. livestock through everyday digestive processes makes enteric fermentation a promising target for emissions reduction interventions. Diet changes, livestock feed additives, and selective breeding have been studied as means of achieving GHG reductions from enteric fermentation (ICF International 2013). However, data on GHG mitigation potential from these interventions are limited. Moreover, interventions that reduce enteric fermentation emissions may also reduce emissions associated with manure management, making it difficult to precisely calculate independent impacts. Nevertheless, studies have shown promising results associated with various feed-based interventions, suggesting that further study may be warranted to more precisely quantify both emissions reductions potential and costs of these practices.

[3] U.S. average sequestration = 1,252 lbs/acre/year (Table 2.11 in Birdsey 1992).

[4] Carbon density per acre derived from Kellndorfer et al. 2012 and Tansey 2017.

Limitations of the Analysis

The methodology used to generate the mitigation potential pricing distribution drew on the results of a number of studies, many of which used different methods and metrics to estimate mitigation potentials of various practices and their associated costs. As a result, pricing estimates may not be perfectly comparable across practices. For instance, some prices were calculated with estimated breakeven prices for practice adoption, while others used economic models to determine the carbon price at which landowners were likely to transition from one land use to another. The length of time considered by different studies in estimating mitigation potential varied as well, with some studies considering impacts only through 2030 and others looking out to 2050 or averaging potential across a longer time period.

Another limitation of this economic analysis is that many of the practices considered elsewhere in this paper were not included due to lack of data or insufficient understanding of how adoption of those practices might affect adoption of other included practices. Practices with significant mitigation potential, such as livestock feed changes to reduce enteric fermentation, use of nitrogen inhibitors on cropland, soil carbon sequestration, and avoided forest conversion, were not included in the quantitative price distribution analysis.

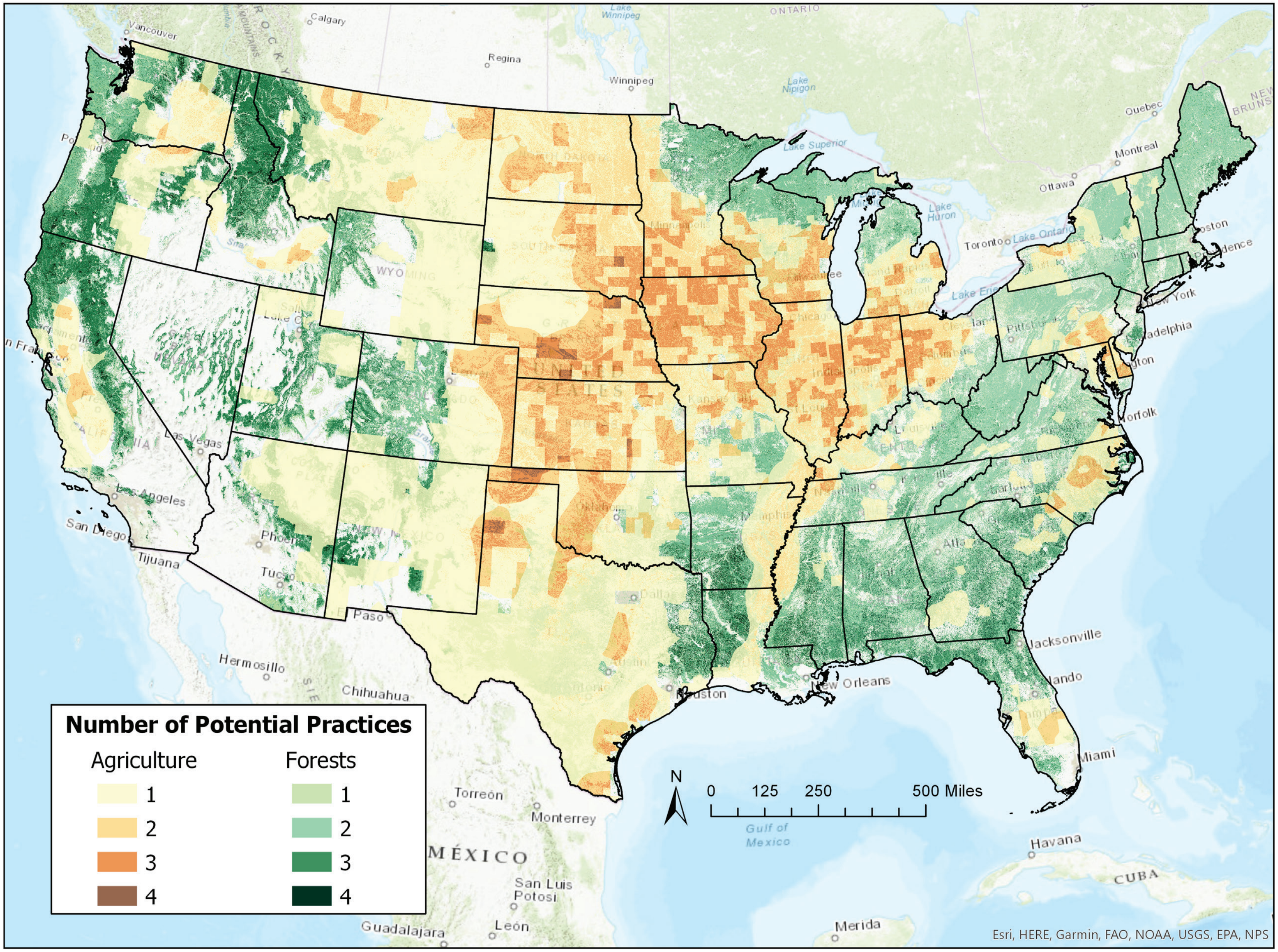
Finally, although precautions were taken to avoid double-counting sequestration potential from multiple practices on the same acreage, the available potential of some practices may be reduced by the full adoption of other practices within the distribution. For instance, large amounts of forest expansion may reduce the potential from transitioning from conventional tillage to no till if the new forest land displaces conventionally tilled croplands. Nevertheless, the analysis presented here suggests that the MCS land sector emissions mitigation goals may be achieved cost-effectively through the implementation of a combination of agricultural and forestry practices. Details of the price distribution analysis methodology are presented in Appendix A.

GEOGRAPHY OF MITIGATION POTENTIAL

Forests and agricultural areas are widespread across the United States, with substantial regional differences in the location of specific cropping systems, livestock operations, and forest ecosystems. Most U.S. states have areas of potential impact for at least one of the climate-smart practices considered in this paper (Figure 2). This consideration suggests that every state can contribute to U.S. climate goals through investments in climate-smart practices in the land sector.

Nevertheless, some regions will be more suited to a particular type of intervention than others, and there is significant value in identifying hotspots with the greatest potential for implementing a given practice. The most effective practices in a given region will be determined by several factors, including the dominant land use systems, land productivity or other characteristics of the natural resources within the region, local sources of GHG emissions, threats to existing carbon stocks, and opportunities to increase carbon sequestration or reduce GHG emissions. For example, when forests are converted to other land uses, they release large amounts of carbon and compromise the future carbon sequestration capacity of the land (The White House 2016). Thus, areas of the country with high rates of forest loss may be prime targets for reforestation and avoided conversion policies and incentives.

Figure 2. Opportunities for implementing climate-smart practices in forests and agriculture in the United States



Source: Map created by Kendall DeLyser, April 30, 2018. Projection: USA Contiguous Albers Equal Area Conic USGS Version

To identify areas of the country suited to particular climate-smart practices, a geospatial analysis of mitigation potential and practice distribution in the United States was conducted. Under the MCS framework (The White House 2016), the analysis focused on the following practices:

Forests

- Reducing the risk of carbon emissions from wildfire through improved forest management (IFM) on public forestlands
- Increasing carbon sequestration through IFM on private forestlands
- Avoiding carbon emissions from forest conversion or loss on private forestlands
- Forest expansion through reforestation on private lands

Agriculture

- Reducing soil carbon emissions through conservation tillage techniques on productive cropland
- Protecting soil carbon in pasturelands
- Managing nitrous oxide emissions by reducing excessive or untimely nitrogen fertilizer applications
- Reducing methane emissions by managing manure and installing methane digesters on livestock farms.

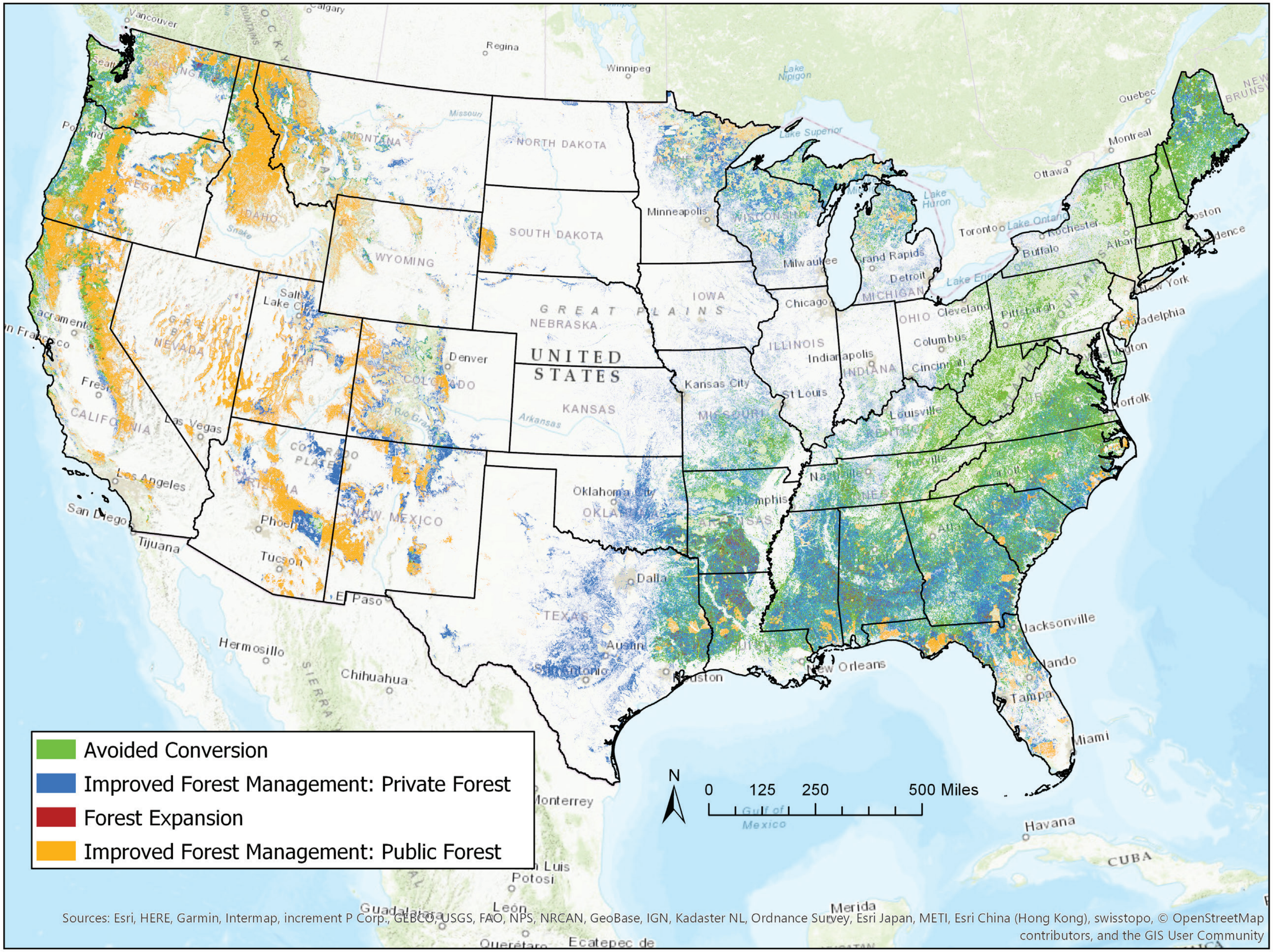
Although the policy recommendations presented here apply nationwide, the geospatial analysis is focused on the conterminous states due to limited data availability for Alaska, Hawaii, and U.S. territories. The analysis was conducted in ArcGIS Pro (Esri 2018) using two sets of data: one for forests and another for agriculture (Appendix Table B1). It used thresholds identified from literature or input data resources to determine whether certain areas represented a potential threat or opportunity for carbon sequestration and GHG emission reductions in forests and agriculture (Appendix Table B2). For example, publicly owned forests with a moderate, high, or very high wildfire hazard potential indicate locations where IFM on public forestlands may be the most effective climate-smart practice to reduce the risk of carbon emissions from wildfire. Details of the geospatial analysis methodology are presented in Appendix B.

The maps created from the geospatial analysis (figures 2–4) demonstrate that opportunities to enhance carbon storage and reduce GHG emissions through agricultural and forestry practices are widespread across the country. They also illustrate some overarching themes and regional trends, discussed below.

Forestry Practices

Forests are a dominant land use in the eastern United States, portions of the Rocky Mountains and Southwest, and the Pacific Northwest. However, the forest types in each region are diverse, and they each face different threats and opportunities for carbon sequestration, so the suitable types of climate-smart forestry practices will vary across the country (Figure 3).

Figure 3. Opportunities for mitigation and sequestration from forestry practices



Source: Map created by Kendall DeLyser, April 30, 2018. Projection: USA Contiguous Albers Equal Area Conic USGS Version

Improved Forest Management on Public Lands

IFM on public forestlands has the greatest potential for impact in the western United States, where a higher proportion of forests are publicly owned. The forests in the West are threatened by catastrophic wildfire, large-scale bark beetle attacks, and other forest health issues, though the analysis in this paper focuses on the risk of wildfire. This category includes publicly owned forests with a moderate, high, or very high wildfire potential, forests where IFM can help reduce the risk of fire and the likelihood of high carbon emissions from a wildfire.

Improved Forest Management on Private Lands

Private forestlands are more concentrated in the eastern United States, so the potential for IFM on private lands is greater there, particularly in the lake states and the Southeast. Climate-smart forestry practices on these lands are likely to focus less on fire and other forest health issues and more on practices that enhance forest productivity and carbon sequestration. For this category, the analysis identified areas with privately owned forestland and relatively low carbon stocks, areas where improving forest management practices can increase carbon sequestration in the forest.

Avoided Conversion

Avoided conversion practices are targeted at private forestlands, which means the greatest potential for impact is also in the eastern United States and especially throughout the Southeast and Northeast. The most common conversion threats to existing forests are agriculture and urban development (The White House 2016), so areas with high growth rates in either of these competing land uses are likely candidates for forest conversion and loss. This analysis focuses on privately owned forest areas with high rates of forest loss since 2000 and relatively high carbon stocks as priority hotspots for avoided conversion policies and incentives to prevent high carbon emissions from forest conversion.

Forest Expansion

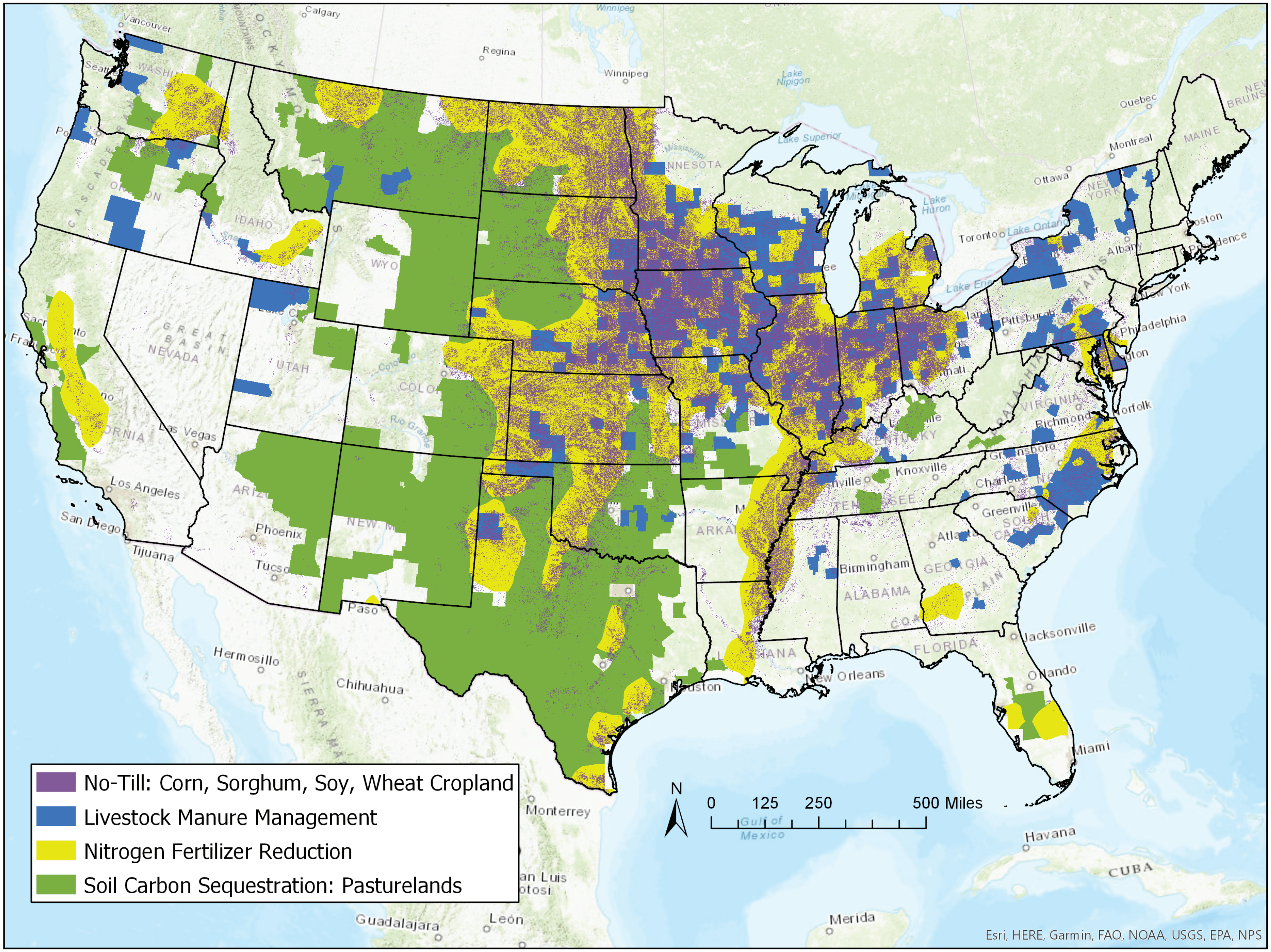
The largest potential for forest expansion on private lands comes from reforestation in the eastern United States, predominately in the South and in the Northeast. However, opportunities for this practice are limited, given competing land uses, and therefore reforestation faces the challenge of achieving the necessary scale (40 million to 50 million acres, according to the MCS) while minimizing displacement of these competing land uses. In Figure 3, the forest expansion category includes private lands historically covered in forest that have recently lost their forest cover.

Forest expansion is also possible on degraded lands (such as areas recently burned by wildfires) or on marginal pasturelands throughout the country. Because of data limitations, this analysis includes neither of these options, though they do offer interesting potential in meeting the MCS goal of 40 million to 50 million acres of new forest. Before reforesting any large area of land, it will be important to ensure that a forest can become successfully established there given the region's climate and land use patterns and that a forest is the best land use for a given location.

Agricultural Practices

Most mitigation potential from agricultural practices will be focused around the Corn Belt, especially Iowa, Illinois, Indiana, Ohio, and the southern portions of Minnesota, Wisconsin, and Michigan (Figure 4). In this part of the country, all four agricultural practices in this analysis overlap, indicating that these states will be valuable contributors to agricultural mitigation efforts. However, each practice also has its own geographic distribution, discussed below.

Figure 4. Opportunities for mitigation and sequestration from agriculture practices



Source: Map created by Kendall DeLyser, April 30, 2018. Projection: USA Contiguous Albers Equal Area Conic USGS Version

Conservation Tillage on Productive Cropland

To match the data used for no-till practices in the price distribution analysis, the geospatial analysis of conservation tillage techniques was limited to no-till practices in corn, wheat, soy, and sorghum cropland. These crops are grown extensively in the Corn Belt and along the Lower Mississippi River, with other areas of production in eastern Washington and the Central Plains. This category does not account for cropland already under conservation tillage practices, but it can help to identify regions of the country with high commodity crop production, regions where no-till policies and incentives may be most effective.

Soil Carbon in Pasturelands

Most potential for increases in pastureland soil carbon exists in the Central Plains, stretching from the Dakotas and Montana in the north down to Texas in the south. In large areas of pastureland, improved management techniques can reduce soil carbon emissions and increase the carbon sequestration capacity of the soil. In this analysis, this category includes any county with at least 30% pastureland by area, where pastureland management practices may have a larger impact on soil carbon.

Nitrogen Fertilizer Management

The Central Plains also show high potential for nitrogen fertilizer management to reduce N_2O emissions. Potential also exists in the Central Valley of California, along the Lower Mississippi River, and in portions of the South. The analysis isolated areas with above-average rates of nitrogen fertilizer applications as potential hotspots for improving management and reducing GHG emissions.

Manure Management

Livestock manure management opportunities are most concentrated in the lake states and along the East Coast from North Carolina to Vermont, though the nationwide distribution of dairies, cattle feedlots, and hog farms means that opportunities exist across the country. This category captures any county with at least 500 head of dairy cows, beef cows, or hogs. However, many counties choose not to report explicit production quantities in order to protect their residents' privacy and therefore could not be included in this analysis. Consequently, opportunities for manure management are more widespread than they appear in Figure 4.

Nationwide Geography of Mitigation Potential

When combined, the geospatial analyses of these practices show that some regions have opportunities for impact in both sectors, while others will be dominated by either forestry or agriculture practices (Figure 2). In most states, the areas of mitigation potential from these sectors are spatially discrete and do not overlap, so there may be less competition between viable practices on the same acreage. States like Wisconsin and North Carolina, however, show significant overlap between their forest and agriculture focus areas (These overlapping zones are shown in Figure 2, where forestry practice areas are visible in green underneath the yellow or orange agricultural areas). These states may provide important opportunities for implementing a range of climate-smart practices and for finding ways for the forestry and agriculture sectors to work together toward reduced GHG emissions. Regardless of the number of practices that may be effective within a given region, this analysis indicates that there are widespread opportunities for each state to contribute to U.S. climate goals through climate-smart land management practices.

Limitations and Areas for Future Research

The analysis presented here provides a useful overview of the distribution of opportunities in U.S. agriculture and forestry to mitigate climate change. There are at least two ways to improve and refine the analysis. First, data gaps could be filled to provide a fuller and more precise analysis. Some of the practices considered here, such as manure management, can be more accurately mapped with more complete datasets. Practices like forest expansion on marginal pastureland show great promise in their mitigation potential, but they require a more in-depth analysis than that presented here.

Second, more localized data would offer more precision that could give federal and state policy makers, agencies, forest and agricultural stakeholders, conservation groups, businesses, and others better insight into where the greatest mitigation opportunities exist. A more detailed study be completed on a state-by-state basis to identify potential opportunities in greater detail and to illuminate the possible benefits from implementing the climate-smart practices discussed here.

Notably, this analysis does not account for stakeholder buy-in or landowner interest in the practices considered here. The maps presented here show the potential areas of impact for forest and agriculture policies, but they are not indicative of likelihood of adoption. Similarly, other external factors affecting forests and agriculture, such as climate change, crop prices, or other policies affecting the land sector, have not been considered here. For this analysis, it was assumed that none of these external factors would have an impact on the potential for implementing the climate-smart practices described here in the United States.

POLICY RECOMMENDATIONS

The analysis suggests public policy recommendations for achieving the MCS land sector GHG reduction goals. One set of recommendations involves potential crosscutting initiatives capable of delivering emissions reductions across multiple land use categories. The remaining recommendations are grouped according to those targeting the agriculture sector and those targeting the forest sector.

Crosscutting Recommendations

The analysis suggests two cross-cutting policy recommendations for incentivizing emissions reductions and sequestration in both the agricultural and forestry sectors: a USDA-housed national carbon bank, which would serve as a retail offset broker for land use-sector GHG offsets, and a significant expansion of USDA's technical assistance services to allow tailored consultation and hands-on assistance to farmers, ranchers, and forest owners interested in implementing GHG-reducing programs.

National Carbon Bank

Overview

Establishment of a national carbon bank could dramatically increase investment in U.S. climate-smart agricultural and forestry practices. The proposed bank would be a voluntary, non-regulatory mechanism aimed at bolstering carbon sequestration and GHG mitigation on farms, ranches, and forestland. It would purchase offset credits from working farms, ranches, and forestlands through reverse auctions, loans, grants, or other mechanisms. Through this process, it would create an effective price floor for agricultural and forestry offset credits in the United States. Purchased offsets could then be held, retired, or sold to private companies and other buyers in the voluntary offset market, or they could be sold into a future federal compliance market in the event that such a program is established.

Structure

The proposed bank would be housed in and administered by the USDA and capitalized with federal dollars. The USDA has strong working relationships with U.S. farmers and ranchers and with other affected stakeholders. Housing the bank within the agency would provide it with the necessary credibility to achieve stakeholder buy-in and encourage wide-scale participation. The bank would function as a retailer of offsets in the voluntary market. As a federally administered entity, however, the bank would not be constrained by the necessity of turning a profit, allowing it to effectively subsidize the production and sale of agriculture and forestry offsets.

In the event that a federal compliance market for carbon offsets is established, USDA could then sell offset credits into the compliance market to companies that seek to offset GHG emissions from their operations in order to meet mandated targets. As part of that program, the USDA could partner with the EPA to ensure the environmental integrity of offsets sold for compliance. In this capacity, the EPA could be tasked with advising and assisting USDA and Bank personnel on bank operations such as protocol selection and design of internal mechanisms for ensuring offset permanence and emissions leakage accounting. The USDA, not the EPA, should continue to oversee individual projects and interface directly with program participants.

Mission and Key Innovations

The primary mission of the proposed national carbon bank would be to create the conditions necessary to significantly scale up adoption of emissions-reducing practices in agriculture and forestry. It could achieve this through the following key innovations:

- Creating a price floor for carbon offsets generated from forestry or agriculture
- Reducing transaction costs for program participants through the use of streamlined monitoring and verification requirements
- Providing supplementary assistance in the form of loans, cost-sharing, and technical assistance to facilitate program participation
- Ensuring the environmental integrity of offsets sold through the establishment of self-insurance mechanisms.

Creating a Price Floor for Land Sector Offsets

The average price of offsets in the voluntary market in 2016 was \$3.00/tCO_2e (Hamrick and Gallant 2017). Even at such low prices, many more offsets were produced in 2016 than were sold.[5] This combination of low prices and volatility of demand, coupled with the relative difficulty of measuring and verifying land-sector emissions reductions, has acted as a deterrent to project developers considering operating in this space. As a result, relatively few offset credits currently on the market come from domestic agriculture or forestry projects.

The primary innovation offered by a central carbon bank is the capacity to change this incentive structure by coupling guaranteed demand for a given volume of land-sector offsets with a transparent, predictable price floor. By selecting projects through a reverse auction, the bank could ensure prices cover project costs while remaining competitive within the land sector. Bank bids could also be structured as put options (i.e, an option to sell assets at an agreed price) so that participants would remain free to sell their credits into other markets if the prices at the time of sale exceed the bank's offer.

Streamlining Monitoring and Verification

Under current protocols in the voluntary markets, it takes an average of two and a half years for an offset project to move from conception to credit issuance (Goldstein and Gonzales 2014). For farmers and landowners with narrow profit margins, this is a long time to wait for an initial investment to begin to pay off. Furthermore, high costs for measuring, monitoring, and verification of emissions reductions, along with requirements intended to ensure additionality of offsets in existing protocols, are viewed as burdensome by many landowners and can act as a barrier to entry to the offset market.

Another innovative role that the proposed bank could play would be to minimize these barriers by developing new, science-based protocols that would streamline requirements for offset certification. The resultant offsets may not meet standards for compliance offset markets, but they could be used by private companies to help meet voluntary emissions-reductions pledges.

Providing Financial and Technical Assistance

In addition to offering a guaranteed price and a streamlined verification process, the bank could offer low-interest loans, grants, or cost-sharing mechanisms to project developers facing high capital costs. These financing mechanisms could be offered through new programs established within the bank or could come from existing USDA programs such as the Rural Energy for America Program (REAP) and the Environmental Quality Incentives Program (EQIP).

The bank might also choose to offer more flexible financing mechanisms. For instance, it might offer program participants a put option on future offsets generated. This mechanism would effectively guarantee the participant the option to sell a given number of offsets at a given price at the agreed-on date. However, if the participant were able to find another buyer at a higher price, he or she would be under no obligation to sell to the bank. The bank might also offer other investors the option to join a purchasing pool in which other organizations would share the costs of investing in an offset project with the resultant offsets being distributed proportionately on the basis of the amount of investment.

[5] In 2016, 18.5 MtCO_2e of offsets were sold in the primary voluntary offset market, compared to 56.2 MtCO_2e of offsets that companies reported unsold (Hamrick and Gallant 2017).

Bank personnel could also offer consultation and technical assistance services, either through the bank or in partnership with existing USDA programs or third-party organizations. Partnering with existing USDA programs would allow the bank to leverage established infrastructure and institutional knowledge. In addition, by working with existing programs, the bank could build on existing landowner relationships to broaden its outreach.

Ensuring Environmental Integrity

Many environmentalists are concerned with the environmental integrity of offsets. In particular, environmentalists have expressed concern with the additionality of offsets as well as the possibility for emissions leakage and reversal of practices. The bank could solve these issues by leveraging its role as a large-scale aggregator of practices to self-insure against losses resulting from leakage, practice reversal, and natural disruptions.

One option is for the bank to maintain a buffer pool of purchased offsets that could be drawn on in the event of practice reversal. This option would differ from the use of buffer pools in existing offset protocols in that the bank, rather than the project developer or the buyer, would assume the liability for practice reversal. This strategy would help to put forestry and agricultural sequestration offsets on a more even footing with other offset categories.

Fostering Collaboration through Partnerships

The proposed bank would be a collaborative initiative with significant nonprofit and private sector engagement and would be structured to encourage collaboration with outside groups, including nonprofits, private sector companies, and other agency departments. Opportunities for collaboration are discussed below.

Selecting and Developing Offset Protocols

The USDA could collaborate with nonprofits, research institutions, and voluntary offset standard bodies to identify existing offset protocols in agriculture and forestry that could be utilized by the bank. The bank could work with these same groups to develop new metrics and protocols if it is determined that new tools are needed to spur wider adoption of emissions-reducing practices in the land sector.

Similarly, the USDA could convene relevant stakeholders from the buyer side of the market to determine the types of offsets sought by buyers. For instance, some private companies that use offsets in order to claim carbon neutrality prefer offset categories that include co-benefits in particular areas such as water quality benefits or worker rights. By seeking input from the companies that it would eventually hope to sell credits to, the bank could ensure that chosen protocols and offset offerings are aligned with buyer preferences.

Maximizing Outreach and Project Development

In addition to working directly with farmers to enroll working farms and forestlands in offset activities, the bank could work with existing offset project developers to maximize outreach and assistance. It would offer an additional avenue for project developers to bring new land-sector offset projects to market.

Administering Audits and Verification

The bank could collaborate with the existing network of voluntary standard bodies to administer on-the-ground project audits and verification services. It could maintain a database of registered third-party auditors from which prospective project participants could choose.

Targeted Technical Assistance

Technical assistance provides farmers and forest owners with the understanding and tools to leverage existing best practices and technologies for successful adoption of climate-smart practices. Because some of these practices are relatively new and somewhat complex, farmers, ranchers, and forest owners may require simplified information from specialists to understand how the practices fit within their existing operations. This shared understanding and streamlined flow of accurate information can lead to greater and more effective adoption of practices. Targeted technical assistance is a critical element of accelerating adoption of the practices and of scaling them to achieve the ambitious MCS goals. Without technical assistance, it will be impossible to achieve the goals related to forest expansion, improved soil health management, or adoption of advanced emissions mitigation technology at the farm level.

The USDA could bolster existing technical assistance through more targeted farmer and forest owner outreach and enhanced hands-on individual consultation services. Although the USDA's network of extension services and conservation programs already provide information on and support for implementing best practices, a more targeted approach for farmers and forest owners is needed to reach the MCS goals.

Several existing USDA programs provide technical assistance and information to farmers and forest owners seeking to implement emissions-reducing practices. However, many of these programs lack targeted outreach. Others may make information available but do not assist farmers that require additional consultation. Individual consultation services are especially critical for encouraging the adoption of highly technical practices, such as installation of anaerobic digesters, or the implementation of land management plans for sustainable forests.

The USDA could expand and improve farmer and forest owner access to targeted assistance in the five ways described below:

Existing Models for the Proposed National Carbon Bank

Pilot mechanisms already exist to promote private sector investment in greenhouse gas emissions reductions in non-regulated sectors through price support for offset markets. Most notably, the World Bank's Pilot Auction Facility (PAF), launched in 2015, functions as a reverse auction for put option bonds on offset credits in the Clean Development Mechanism. To date, the World Bank has run three PAF auctions and issued $54 million in bonds, representing 20.6 MMT CO_2e.[b] In 2017, The Climate Trust announced the Environmental Price Assurance Facility (EPAF) for U.S. offset credits, based on the World Bank PAF model. The launch of EPAF was supported by a $900,000 Conservation Innovation Grant from the U.S. Department of Agriculture.[c] The EPAF expects to conduct its first auction in the third quarter of 2018.[d]

Other mechanisms are now under consideration. The California Air Resources Board (CARB) is evaluating a put option or a "contracts for difference" mechanism, in which the credit seller pays no premium but must pay any upside difference between the market credit price and the strike price, for Low Carbon Fuel Standard (LCFS) credits from dairy and livestock projects.[e] CARB is acting under a legislative directive to "develop a pilot financial mechanism to reduce the economic uncertainty associated with the value of environmental credits."[f]

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[a] The World Bank, World Bank Pilot Auction Facility Unlocks Capital Markets for Climate Action, Press Release (2017), http://www.worldbank.org/en/news/press-release/2017/12/07/world-bank-pilot-auction-facility-unlocks-capital-markets-for-climate-action.
[b] World Bank Group, Pilot Auction Facility, https://www.pilotauctionfacility.org/.
[c] Krifka, K., USDA Awards $900K Conservation Innovation Grant to The Climate Trust, The Climate Trust (2017), https://climatetrust.org/usda-awards-900k-conservation-innovation-grant-to-the-climate-trust/.
[d] The Climate Trust, Environmental Price Assurance Facility, https://climatetrust.org/portfolio/environmental-price-assurance-facility/.
[e] California Air Resources Board, SB 1383 Pilot Financial Mechanism, Transportation Fuels Branch, https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/062617presentation.pdf.
[f] Ibid.

Identifying Potential Opportunities for Technical Assistance and Streamlined Processes

The USDA may choose to first review each program for its current technical assistance capacity and to identify opportunities for more targeted assistance to farmers and forest owners. A program review could be incorporated in the normal reporting structure of the USDA. A dedicated staff person or small committee could coordinate the process to create a standard review form for identifying existing technical assistance programs and for ensuring that programs and departments understand the purpose of the review.

Programs might find they have limited staff to address the great demand from farmers and forest owners or that their paperwork or tools are too complex for farmers and forest owners to use. Other programs may find that the processing time for applications is much longer than necessary or that applications for multiple programs could be streamlined to minimize the amount of time spent on paperwork. For example, the USDA could find that the paperwork required for EQIP grants is too burdensome for small to medium-sized farms or landowners and that a simpler application could increase participation and applications to the program.

Once these opportunities for more assistance or streamlined processes are identified, the USDA could match those identified needs with solutions and funding to build capacity in individual programs. From this review process, the USDA could also identify programs for which enhanced technical assistance is not feasible at the national level but may be at the state or extension level.

Developing Improved Metrics on Technical Assistance

The USDA may choose to develop and utilize metrics to measure the efficacy of technical assistance in its programs. Because empirical data on how different technical assistance approaches affect adoption of practices is lacking, enhanced data collection and evaluation could help staff better understand the most effective outreach and consultative services. The development and incorporation of metrics related to technical assistance could be incorporated in the normal program review structure of the USDA. A dedicated staff person or small committee could coordinate the metrics development process by creating standard metrics and assisting program staff with incorporating applicable metrics into their reporting processes.

USDA programs could track the number of hours spent on technical assistance for various projects and determine their impact on the successful adoption of practices. The USDA could also track the time it takes between application for a program or requests for technical assistance and receipt of assistance. Improved metrics and data evaluation can ensure that the enhanced technical assistance has the intended impact on practice adoption and program participation.

Building Capacity in Individual Programs

The USDA may choose to enhance technical assistance and consultative services in existing programs. Dedicated staff could work directly with interested farmers and forest owners to evaluate onsite potential and explain complex technical tools to be used in existing programs. The envisioned expansion of individualized consultation services would ensure farmers and forest owners use the most effective practices and face the fewest challenges while adopting these practices.

Building Capacity at the State Level through Grants

Rather than directly hiring additional staff, the USDA may choose to offer grants to state governments to more closely tailor personnel and programs to the prevailing needs in their jurisdictions. For instance, the state of Iowa may be more interested in establishing programs to encourage adoption of soil sequestration practices in cornfields, whereas the state of North Carolina may be more interested in technical assistance programs for hog farmers considering adoption of anaerobic digesters

Examples of Existing Opportunities for Enhanced Consultative Services

The U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency currently collaborate on the AgStar program to provide technical information to farmers interested in installing anaerobic digesters. AgStar's reach and efficacy could be greatly expanded if it hired personnel to assist interested farmers with using the tools AgStar provides. The USDA could use best practices from states like California, New York, and Vermont, which provide ombudsmen who guide farmers through every step of adoption of these highly-complex systems.

Similarly, the Natural Resources Conservation Service (NRCS) offers cost-share payments to farmers and forest owners to implement conservation practices through the Environmental Quality Incentive Program (EQIP), but research suggests that the program has historically fallen short of its goals, at least in the forestry sector, due in part to a lack of outreach to small forest owners.[a] The efficacy of programs like EQIP would be enhanced by bringing on personnel who have existing relationships with targeted farmer and forest owner constituencies and local knowledge of appropriate conservation practices for targeted sectors. These personnel could include regional NRCS and U.S. Forest Service staff, state agency staff, and practitioners with nonprofit groups that align with the program's goals.

[a] See, e.g., Jacobson, M.G., T.J. Straka, L. Greene, M.A. Kilgore, and S.E. Daniels, "Financial Incentive Programs' Influence in Promoting Sustainable Forestry in the Northern Region," *Journal of Applied Forestry* 26(2): 61–67.

on their operations. On the forestry side, grants may include targeted assistance to private forest owners to enhance fire resilience through improved forest management practices or assistance to wood product manufacturers to develop local demand for forest products, depending on regional priorities.

The USDA could use the innovative grants to leverage additional funding from state governments through matching funds and to scale best practices to meet regional or national needs. Existing grant programs like the Conservation Innovation Grants (CIG) could be applied for this purpose, but the envisioned technical assistance grants would be broader in scope and not tailored specifically for one program or practice. One benefit of providing funding through innovative grants is that it would allow the USDA to leverage additional funding from state governments through matching funding requirements or other similar provisions. Additionally, this approach would allow best practices—such as the targeted ombudsman approach outlined above—to be distilled from variations in state programs and scaled to meet regional or national needs.

Partnering with Private Business to Promote Practices

The USDA may choose to strengthen public-private partnerships with producer associations, private agribusiness and forest product companies, and nonprofit organizations to provide technical assistance. Farmers and forest owners trust these institutions when exploring new practices or technology, and the USDA could create specific designations for private companies providing direct assistance for implementing improved practices. The USDA should work with stakeholders from these groups to understand what might be most effective and feasible.

Public-private partnerships could incentivize these associations and companies to encourage and support farmers and forest owners in adopting new practices, ranging from improved fertilizer management and no-till management to improved forest management and agroforestry. For example, a fertilizer company could partner with the USDA to share best fertilizer management practices with farmers and to help farmers understand how to incorporate those practices in their existing operation. The USDA could create specific designations of private companies providing direct, technical service on improved practices. It should work with stakeholders from relevant industries and producer groups to understand what might be most effective and feasible for future partnerships.

Agriculture Recommendations

Achieving agricultural emissions mitigation will require a focus on reducing existing emissions from sources such as enteric fermentation, livestock manure, and nitrogen fertilizer application as well as enhancing soil carbon sequestration on crop and rangelands through practices such as no-till farming and nitrogen management. The analysis presented here suggests two strategies for encouraging GHG mitigation and carbon sequestration in the agricultural sector: (1) establishment of a new voluntary consensus standard for environmental best practices in agricultural production and (2) enhanced data collection in support of the establishment of crop insurance premium subsidies for implementing climate-smart practices.

Certified Climate-Smart: A New Climate-based Producer Certification

As mentioned above, the MCS sets ambitious targets for reducing agricultural GHG emissions and enhancing carbon sequestration on U.S. agricultural lands. Achieving these goals will require significant new investment to bring existing land use in line with environmental best practices—more investment than can be supplied by existing federal incentive programs alone. The private sector, as the buyer of most agricultural products, has a vital role to play in closing this gap. Accordingly, the envisioned role of government is facilitating private engagement with and investment in climate-smart practices by agricultural providers.

Private companies, including food and beverage companies, have expressed interest in reducing the emissions of greenhouse gases from their supply chains (Ceres 2016). These companies engage in various types of relationships with their agricultural suppliers as they seek to influence supplier practices. These relationships vary on the basis of the company's mission and level of engagement and may range from the imposition of minimum standards or requirements through purchasing contracts to more hands-on cooperation in the development of detailed agricultural management systems with contracted suppliers (OECD-FAO 2016).

Presently, companies seeking to "green" their supply chains have done most of the legwork in developing and implementing standards and practices that suit their particular goals, investing substantial resources in the process. As more companies pursue carbon neutrality and other environmental goals in their supply chains, however, there may be a growing need for a more standardized process whereby companies can identify and engage with suppliers that have committed to utilizing environmental best practices.

The USDA could help to facilitate the growing movement of environmental supply chain reform by filling the following roles:

- Convening a federal advisory committee to bring together companies, farmers, nonprofits, and other industry groups and stakeholders to determine the barriers and challenges to adoption of climate-friendly agricultural practices and the needs of these groups for standardized environmental management systems and processes
- Facilitating the development of voluntary multi-stakeholder consensus standard(s) that meets the needs of companies seeking to implement supply chain reform—standards perhaps based on the outcomes of the above information-gathering process and generated through the standard-developing process set by the International Organization for Standardization (ISO)
- Providing auditing and certification services, through the USDA's Agricultural Marketing Service (AMS), for producers and suppliers who are interested in adopting or implementing the resultant standard(s)[6]
- Providing technical assistance and cost-sharing through grants or loans to farmers and suppliers interested in transitioning practices to meet the new standard(s)
- Enhancing the collection and dissemination of data on the climate impacts of various agricultural practices in support of science-based policy making.

Several types of standards or certifications may be useful to private companies as they seek to reduce agricultural emissions in their supply chain. Companies have different goals and interests that they pursue when greening their supply chains. By involving many stakeholders in the standard-development process, the USDA could ensure that any labeling or certification program(s) that emerges from this process would be based on the needs of the companies instituting the changes. This strategy may result in the development of multiple standards targeting separate environmental outcomes (e.g., separate certifications for climate-smart practices, water efficiency, and nutrient run-off management), a single, comprehensive standard incorporating all of these outcomes (e.g., a "regenerative agriculture" certification), or some combination of possibilities.

Convening many stakeholders in the process would also allow the USDA to work collaboratively with outside groups that are already in the process of developing and testing food, fiber, and fuel supply chain monitoring and management systems. The USDA has partnered with third-party organizations on similar programs. These organizations have contributed knowledge and expertise in the standard-development phase, generated standards through outside processes with the USDA agreeing to provide verification services, and providing services as on-the-ground, third-party auditors in support of the USDA's existing programs. The USDA may determine that there are existing third-party-developed standards for which it could provide supporting verification services, or it may determine that there is a market need for a new standard. The USDA's level of involvement in the development of the standard will determine the authorities and budget that will be required.

Participation in any resulting program(s) could be voluntary for farmers and food manufacturers, but it could be encouraged through development of a public-private partnership between the USDA and companies that are willing to sign on to a pledge to transition the agricultural components of their supply chain to climate-smart practices. In exchange for participation in the program, the USDA could work with the company's suppliers to offer subsidized technology transfer and technical training to facilitate farmer alignment with the agreed-on standard.

[6] The AMS administers voluntary auditing and accreditation services for a number of agricultural standards. A climate-smart practices standard fits within the scope of existing AMS-administered producer-accreditation programs such as the Grass Fed Program for small livestock producers, the Animal Welfare accreditation, and the Non-Hormone Treated Cattle Program.

A new voluntary consensus standard for climate-smart agricultural practices would likely be relatively inexpensive to establish and administer. The AMS's existing auditing and industry-marketing claim verification services are funded through user fees and licenses. Expanding the AMS's services to include verification of a marketing label based on climate-smart agricultural practices would likely not require additional appropriations. However, if the USDA became involved in a broader effort to develop, administer, and market a consumer-facing label with a scope like the National Organics Program, additional funding would be needed. On the basis of similar programs, it appears that a popular consumer-facing label would need an annual budget of at least $2.5 million. The USDA could replicate the structure and apply best practices from other programs to ensure fiscal effectiveness.

Enhanced Data Collection and Incentives: Crop Insurance

Crop insurance provides farmers protection from risks related to market price changes or natural disasters. Climate change will dramatically increase the frequency of climate-related risks and affect farmers' yields. However, carbon sequestration practices like conservation tillage can mitigate GHG emissions from agriculture while improving the resilience of crops to environmental stressors. Farmers who adopt these practices should be rewarded through federal crop insurance policies for helping to create more resilient agricultural systems and reduce the risk of crop losses and insurance payouts.

Approximately 90% of cropland, or 300 million acres, is covered by crop insurance. Producers spend some $3.5 billion for crop insurance, and there is more than $100 billion of liability protection.[7] A majority of producers of commodity crops, including those that require high inputs of fertilizer, enroll in federal crop insurance programs and receive payments when market prices fall below predetermined levels. Using the existing infrastructure of crop insurance to incentivize climate-smart practices could dramatically increase the number of farmers adopting these practices and influence the types of practices adopted, helping to achieve the MCS goals of improved soil health and management.

The analysis presented here suggests two key recommendations for existing crop insurance programs: (1) enhancing data collection on the link between climate-smart practices and crop yields, and (2) using crop insurance premium subsidies to incentivize climate-smart practices.

Strengthening Data Collection

The USDA's Risk Management Agency (RMA) should strengthen data collection from producers participating in crop insurance programs. Better data on yields, practices, and co-benefits from more producers adopting current climate-smart practices would allow the agency to ascertain important information on the impact of mitigation and sequestration practices on yields. Farmers can be hesitant to adopt new practices without evidence of their impact on yields and production. Improved data and analysis can dispel myths of the impacts of fertilizer changes or new practices and can help identify the most effective climate-smart practices on improved crop resiliency. Improved data collection and analysis of production data would further allow the RMA to confidently structure a program incentivizing specific practices.

Previous Changes to Crop Insurance

Changes in crop insurance premiums are relatively rare because of the complexity involved. The Federal Crop Insurance Corporation (FCIC) has allowed discounted crop insurance premiums for corn producers because of biotech yield endorsements. In 2007, producers who used Monsanto products received a discount on their federal crop insurance because Monsanto demonstrated that its patented technology provided lower yield risk than non-genetic inputs.[a]

More recently, in fall 2016, the Iowa Department of Agriculture and Land Stewardship worked with the U.S. Department of Agriculture's Risk Management Agency to establish a demonstration project whereby farmers received a $5 per acre reduction on their crop insurance premium for planting cover crops. More than 1,000 farmers participated in the demonstration project, and the state provided $4.8 million in matching funds to support the cost-share program.[b]

[a] Risk Management Agency, *Frequently Asked Questions: Biotech Yield Endorsement.* U.S. Department of Agriculture, https://www.rma.usda.gov/help/faq/bye.html.
[b] Iowa Department of Agriculture. *Ag in Review.* Iowa.gov, https://www.iowaagriculture.gov/press/2017press/press12262017.asp.

[7] Crop Insurance Information. (2017). *An Introduction to Crop Insurance.* National Crop Insurance Services. Retrieved from https://cropinsuranceinamerica.org/an-introduction-to-crop-insurance/.

Incentivizing Climate Smart Practices

The USDA's RMA should consider modifying existing crop insurance programs to reward farmers who use climate-friendly practices that increase crop resilience in the face of drought and other risks. Producers who implement best practices, such as improved nitrogen fertilizer management, could receive a discount rate on crop insurance premiums. Producers who choose not to implement the practices would continue to secure crop insurance premiums at the same price as before.

Given the complexities of crop insurance premiums, USDA's RMA could consider pilot programs using the empirical findings from the enhanced data collection outlined above.

Forestry Recommendations

The 751 million acres of forestland in the United States are split between public and private ownership. Public and private forest owners face different barriers in managing, expanding, and preserving their forests and so will require distinct policy prescriptions to promote carbon sequestration on their lands. For the largest manager of public forests, the U.S. Forest Service (USFS), inadequate funding for the national forest system has been the primary barrier to forest management and restoration. That barrier could be overcome with establishment of a dedicated USFS fund for enhancing forest resilience on public lands. Private forest owners are already served by a variety of USDA-run conservation incentive programs, but these programs often lack the resources, the technical capacity, or the scope to effectively promote carbon sequestration on private forest lands. Recommendations for addressing this concern are enhancing incentives for private forest management and restoration, expanding the Forest Legacy Program, and adapting the Conservation Reserve Program to reforest marginal pasturelands. Finally, to make forest expansion across the United States an economically viable proposition, markets for wood products should be expanded.

Forest Resilience on Public Lands

With 44% of U.S. forestland under public ownership, public lands—particularly the National Forest System—have an important role to play in meeting MCS goals through improved management and restoration (USDA 2008). Yet forests on public lands face increasing threats. According to the USFS, wildfire costs have consumed increasing amounts of the agency's budget over the last 13 years. In 1995, the USFS spent 16% of its total budget fighting wildfires. In 2017, this number increased to 56% of the budget, or $2.4 billion (USFS n.d.-a). Skyrocketing wildfire costs have prompted a 32% decrease in National Forest System funding from 1995 to 2015, making publicly owned forests unhealthier and at greater risk for future wildfires (USFS 2015).

The FY2018 Omnibus Spending Package, signed into law on March 23, 2018, partially solves this funding gap for forest management. The Omnibus fundamentally changes the way that the USFS pays for wildfire suppression beginning in 2020. It will prevent the agency from using funds from its non-fire program areas for fire suppression during costly fire seasons, enabling it to dedicate those funds for the uses for which they were intended (USDA 2018). Keeping public forests healthy and resilient, however, will require further action to prioritize proactive efforts to reduce future risk of wildfires and to protect ecosystem services, including carbon sequestration and storage, currently provided by public forests.

The USFS could designate a new "forest resilience" set-aside in its annual budget for improved forest management (IFM) practices that will enhance the resilience of public forest land to future wildfires and other impacts of climate change. Creation of the set-aside would be responsive to USFS's own finding that adequately managing the buildup of hazardous fuels in national forests will require an increase in the rate of fuel treatment, with "proactive wildfire management" playing a critical role (Vaillant 2016). In addition to meeting USFS's own needs for wildfire risk reduction, proactive management of national forests is critical to meeting MCS goals on public lands.

The envisioned forest resilience set-aside would combine elements of current USFS line items for Hazardous Fuels, Vegetation & Watershed Management and for Wildlife & Fisheries Management, though it would not replace these programs entirely. The set-aside could, however, help make up for existing funding shortfalls in these other programs, which are integral to fire prevention. IFM practices funded under the set-aside should include clearing fallen and standing dead wood, thinning overstocked forests, and setting prescribed burns where appropriate to reduce the threat of catastrophic fires. A reduction in the risk of large fires will enhance the forests' capacity to store carbon over the long term, while also making forests more resilient to drought, insects, and disease (Loudermilk, Scheller, Weisberg, and Kretchun 2017).

The set-aside could also be used to plant heat- and drought-tolerant native tree species in areas that have been disturbed by fire, thereby enhancing the resilience of those areas to future stresses while increasing their potential to sequester carbon. Asof 2004, the USFS already had a backlog of 900,000 acres of national forest land in need of reforestation—an acreage representing nearly six times the agency's reforestation activity in the previous year (GAO 2005). This backlog had been growing since 1999 as a result of increased incidence of wildfire in the West (GAO 2005). To increase carbon sequestration and enhance ecosystem health on public lands, the USFS must invest in accelerating reforestation efforts to address this backlog.

Importantly, the proposed forest resilience set-aside can also help the USFS establish a network of forestry practitioners to share best practices and technical expertise with regard to fire- and climate-resilient forest management. Forests' response to management interventions such as thinning or prescribed burns can vary considerably among both regions and particular species, so it is critical that forest managers have access to information about best practices in their specific environments (McNulty 2018). The network should therefore be made up of regional chapters and should include representatives from the USFS, the Natural Resources Conservation Service (NRCS), and state forestry agencies, along with forestry practitioners from civil society and academia.

Managing and restoring national forests will also require a substantial labor force. A significant portion of the proposed forest resilience set-aside budget is envisioned to go to hiring workers in predominantly rural areas around national forests to clear hazardous fuels, thin diseased and suppressed trees, prepare disturbed sites for reforestation, and plant new trees. Thus, this policy recommendation will provide a significant opportunity for rural employment at the same time that it makes public forest lands more fire-resilient and contributes to MCS carbon sequestration goals.

Incentives for Private Forest Management and Restoration

Expanding EQIP

The Environmental Quality Incentives Program (EQIP) specifically targets non-industrial private forest land for cost-share assistance on forest management and restoration projects, which are critical to enhancing carbon sequestration and forest resilience. Family forest owners own one-third of all forest land in the United States, making them a key and underserved constituency for achieving the carbon sequestration goals in the MCS (USDA 2008). Much of the non-industrial private forest land across the United States is threatened by development and disturbances such as wildfire, with significant ramifications for GHG emissions from the forestry sector. The USFS found that more than 57 million acres of private forest land could be threatened by increased residential development alone between 2000 and 2030 (Stein et al.).

EQIP is among the only federal programs that currently provide small private forest owners the upfront capital and technical assistance necessary to expand, improve, and manage their forest resources for increased carbon sequestration as well as other conservation values. Although almost 10% of EQIP funding nationally goes to forestry projects, significantly more resources are needed to facilitate the scale of IFM on small-scale private forest lands envisioned in the MCS. That shortfall suggests that Congress increase the appropriated budget for EQIP by some $100 million, with greater increases in the future, to fund new initiatives to help private forest owners manage and retain their forests as a way to meet MCS carbon sequestration goals.

The NRCS has significant discretion to focus EQIP dollars on important conservation challenges. In states with substantial forest resources, the NRCS can use EQIP to invest in conservation practices already covered by EQIP that enhance carbon sequestration on private lands, including Tree/Shrub Establishment, Forest Stand Improvement, and Silvopasture. NRCS regional initiatives like the Longleaf Pine Initiative in the Southeast can help focus EQIP investments on specific conservation priorities in key regions. Additional appropriations for EQIP could fund similar initiatives for improving carbon sequestration in family-owned forests by targeting IFM in regions with understocked forests and with other significant forest conversion risks.

Building State Capacity for EQIP

The NRCS's state offices are key in implementing NRCS regional initiatives (as they are in implementing all of NRCS programs). In states with significant forest resources, state-level spending on EQIP forestry projects is highly variable, ranging from 3% to 36% of states' EQIP funding.[8] States devoting less of their EQIP funding to forestry commonly suffer from a lack of forestry capacity in their NRCS branches. In many states, the NRCS is not familiar to many forest owners, and outreach in the program is lacking (Greene et al. 2010).

[8] Rita Hite, personal communication, March 8, 2018.

To bridge that gap, the NRCS could recruit state forestry agencies to serve as technical service providers (TSPs) who help forest owners implement EQIP conservation practices. By building capacity through collaborations with state forestry agencies as well as the USFS, the NRCS can overcome internal gaps in expertise at the state level and better position itself to support new EQIP initiatives and increased funding for forest management.

Strengthening Incentives through the Forest Carbon Incentive Program

Although EQIP provides strong incentives to manage and restore forest land for small private forest owners, the income cap on program participation excludes large and industrial landowners. These landowners include timber investment management organizations (TIMOs) and real estate investment trusts (REITs), which could provide significant carbon sequestration benefits by adopting IFM practices, as well as industrial-scale farmers and ranchers, who could increase carbon stocks on their land by establishing agroforestry or silvopasture operations. Enhancing carbon sequestration on industrial forest and agricultural land is essential for meeting the ambitious targets in the MCS. Therefore, it makes sense to incentivize these large landowners to adopt carbon sequestration practices through a new USDA program that builds on EQIP and the Conservation Stewardship Program (CSP).

The proposed Forest Carbon Incentive Program (FCIP) would provide cost-share assistance and performance-based incentive payments for private landowners of all sizes to pursue practices that enhance carbon sequestration in tree biomass. Eligible practices for FCIP could include

- IFM practices, including extending rotation ages, improving regeneration after harvest, thinning to encourage growth, increasing forest stocks in understocked areas, and increasing the efficiency of harvest and wood use
- Conservation forestry
- Reforestation of areas affected by wildfire or other natural disturbances
- Agroforestry/silvopasture.

Projects applying to the FCIP would be selected on the basis of their magnitude of carbon sequestration and climate resilience. Practices could be prioritized on landscapes where they will be most effective through a landscape-level project selection process similar to that used by the existing Regional Conservation Partnership Program (RCPP). Owners of all selected projects would sign contracts with the USDA of between 15 and 30 years, with greater incentives offered for longer contract terms.

Forest Legacy Program Expansion

Forests account for roughly 90% of the annual carbon sink in the United States, sequestering an average of 670 MMT CO_2e per year (U.S. EPA 2018) and storing 95 billion metric tons (BMT) CO_2e (U.S. EPA 2015). The loss of forestland is a serious threat to this carbon sink; the conversion of forest to alternative non-forest land uses can both increase emissions from existing carbon stocks and reduce the future carbon sequestration capacity of the land. Therefore, keeping forests as forests will be critical to reaching the MCS goals.

The greatest threat to existing forests in recent years has been residential development, though conversion to cropland has also been a driver of forest loss (The White House 2016). More than 57 million acres of private forest are expected to see a substantial increase in housing density by 2030 (Stein et al. 2009). Avoiding the conversion of 13 million acres of these forests could protect their current carbon stocks and avoid the loss of 40 MMT CO_2e of sequestration by 2050 (The White House 2016). USFS programs like the Forest Legacy Program (FLP) can help protect these forests through cost-sharing conservation easements or fee-simple property sales to the state or to another government agency.

The FLP's forest conservation and carbon sequestration capacity could be expanded though a carbon-focused pilot program. The proposed FLP-Carbon would be a subset of the FLP with a similar operational structure for protecting land. Unlike the current FLP, which selects forest lands for participation on the basis of diverse environmental, social, and economic criteria, FLP-Carbon would prioritize those projects that increase carbon sequestration on working forest land. Extensive stakeholder consultation would be critical in making these adjustments and designing new project selection criteria to ensure that the structure is both user-friendly and environmentally sound.

Funding for FLP-Carbon should be in addition to current appropriation levels, which average $50 million to $60 million annually. The FLP is a popular program with conservation groups, and demand for funding regularly exceeds the program's current limits. With increased funding, the FLP could feasibly expand its capacity. New funding could continue to be administered by the Land and Water Conservation Fund but should be funneled into FLP-Carbon to create a parallel branch of the program without affecting the existing FLP structure or process. The pilot program could be started with a slightly smaller appropriation than that of the current FLP, and then the allocation for FLP-Carbon could be increased to scale up its conservation impact as lessons are learned. The proposed FLP-Carbon would require extra staff to engage with landowners and other involved parties and to oversee the new project selection process. Technical assistance would be a critical element of FLP-Carbon, especially regarding the implementation of practices that increase forest carbon sequestration. These auxiliary needs would have to be addressed as the FLP is expanded.

Reforesting Marginal Pastureland

The Conservation Reserve Program (CRP) is already among the most successful carbon sequestration policies in the United States. Through sequestration and emissions reductions, it has an annual carbon benefit of 43 MMT CO_2e—equivalent to taking nearly 8 million cars off the road. Originally enacted by Congress in the 1985 Farm Bill to combat high rates of soil erosion and to manage crop supplies in the face of low commodity prices, the CRP financially compensates landowners who remove cropland from production through land rental payments and cost-share assistance for land restoration practices. Since its inception, the CRP has enrolled up to 37 million acres of marginal cropland in rental contracts of 10 to 15 years; some 23.5 million acres are enrolled currently (Stubbs 2017).

The CRP can be a powerful policy tool to help meet the MCS goal of 40 million to 50 million acres of reforestation across the country. It provides 10-year rental contracts to landowners who plant trees on marginal cropland as well as compensation equaling up to 90% of the planting costs for trees planted in areas that benefit drinking water supplies (USDA n.d.). Special CRP initiatives for threatened forest types, including longleaf pine and bottomland hardwoods, have resulted in nearly 200,000 acres of forest restoration (Stubbs 2012).

As much as the CRP has contributed to reforestation efforts and carbon sequestration in the United States, there is still considerable room to increase the program's impact. First and foremost, it should expand land eligibility to marginal pastureland across the United States for reforestation practices. The NRCS has estimated that some 74 million acres of pasture and hay-producing land would provide greater environmental benefits through implementation of some conservation practice, which could include planting trees for either reforestation or silvopasture (Sanderson, Jolley, and Dobrowolski 2012). Making this land base eligible for the CRP could greatly accelerate the nation's progress toward the MCS reforestation goals without significantly affecting the land resources available for crop and livestock production.

Other Proposals to Enhance Forest Carbon Sequestration

The opportunity to enhance carbon sequestration in U.S. forests through incentive payments has been recognized both inside and outside the federal government. In 2011, the Pinchot Institute for Conservation issued a report on landowner incentives for forest carbon sequestration that recommended a voluntary incentive program, similar to the Natural Resources Conservation Service's Environmental Quality Incentive Program (EQIP), for private forest owners that would be administered by state agencies in cooperation with federal agencies.a In 2015, Sen. Jeanne Shaheen introduced the Forest Incentives Program Act (S. 1733), a bill that would have established a pay-for-practice incentive program for forest management practices that increase carbon sequestration. A policy paper released by the Forest Carbon Working Group similarly emphasizes the need to modify federal conservation programs in order to restore and manage private forests, though that report focuses on incorporating climate mitigation and adaptation components into existing programs like the Conservation Reserve Program and Conservation Stewardship Program. None of these proposals has addressed agroforestry, but the U.S. Forest Service recently released a report detailing the significant benefits of agroforestry for greenhouse gas mitigation, food security, and ecosystem services.[b]

[a] Pinchot Institute for Conservation. (2011). Forest carbon incentives: options for landowner incentives to increase forest carbon sequestration. Working Paper. Accessed March 26, 2018 from http://www.pinchot.org/gp/Forest_Carbon_Incentives.
[b] Patel-Weynand, T., G. Bentrup, and M. Schoeneberger, Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions. U.S. Department of Agriculture (2017), https://www.fs.fed.us/research/publications/gtr/gtr_wo96a.pdf.

Given that the CRP's current acreage is approaching the congressionally set enrollment cap of 24 million acres, expansion of CRP's scope would require a concurrent increase, ideally to historical levels of 32 million to 36 million acres. Raising the enrollment cap in conjunction with reducing payment rates, as has been suggested, is not suitable for this proposal. To realize the ambitious reforestation goals in the MCS, the CRP would need to provide a sufficient financial incentive for pastureland owners to enroll their property in the program rather than convert it to cropland or another agricultural use. Although payment rates may be sufficient in the current environment of low commodity prices, the CRP should be structured so that its rates remain competitive if commodity prices rise in the future. Both strong financial incentives and wide eligibility of marginal lands are necessary to allow the CRP to maximize its potential for environmental and carbon sequestration benefits.

Expanding Markets for Wood Products

To make the ambitious reforestation goal in the MCS economically feasible, most of the newly forested area would have to rely on revenues from the sale of timber and other forest products. This increase in forest product sales could in turn flood markets for wood products. A sudden increase in supply would cause prices to fall, thereby disincentivizing further forest expansion and creating a negative feedback cycle.

To combat such a market distortion, all levels of government could take action to promote the growth of wood products for construction applications. In addition to supporting the MCS forest expansion goal, growing wood markets would further support GHG emissions reductions by storing carbon in long-lived wood products and displacing the use of emissions-intensive materials like steel and concrete. Significant progress on expanding wood markets has already transpired thanks to the efforts of the USFS and others, so these recommendations are aimed at substantially scaling up existing efforts and ensuring a level playing field for wood products in the construction industry.

Promoting Wood Products

The wood products industry, for its part, can widen its market opportunities by exploring the feasibility of a new check-off program for wood as a building material that particularly emphasizes the environmental and carbon benefits of wood. This program could model its promotion strategies on the successful check-offs for milk ("Got Milk?") and beef ("It's What's for Dinner"). Unlike the softwood lumber check-off implemented in 2011 (Softwood Lumber Board n.d.) and the attempted hardwood lumber check-off that was ultimately abandoned in 2015, the proposed check-off would include all solid wood building material producers and would seek to elevate the market position of all participating products equally. To succeed, however, this check-off effort would need to learn from the lessons of the failed hardwood lumber check-off, which failed to unite a heterogeneous field of small producers (U.S. Endowment for Forestry and Communities 2016).

The wood products industry should also engage in active dialogue with the U.S. Green Building Council to secure favorable treatment in the latter's LEED standards for the carbon storage value and reduced GHG emissions associated with wood buildings construction. This discussion can build on previous successes of the partnership between the industry and U.S. Green Building Council, including the 2016 establishment of the Alternate Compliance Path credit for LEED-certified buildings constructed with sustainably sourced wood products (WoodWorks 2016). Building relationships with other national, regional, and local green building organizations may also help to spur demand for wood products in construction and can enhance the products' reputation as sustainable construction materials.

Accelerating Innovation Through Demonstration and Capacity Building

The federal government can make a large impact on the industry with relatively small investments. To promote continued innovation, the USDA should expand its $7 million Wood Innovations Grant program and sponsor additional rounds of its Tall Wood Building Competition, which distributed $3 million in prizes when it was held in 2015. The USDA should also continue to lead research efforts into the life-cycle benefits of wood products, which could lead to greater recognition of the value of wood products in green building standards like LEED. These activities would all be mandated under the Timber Innovation Act of 2017 (S. 538), which is currently being considered by Congress.

The USDA can also accelerate adoption of wood building materials by continuing its support of training and technical assistance programs through organizations like WoodWorks and by expanding collaborations with other federal agencies to explore the use of new-generation wood products like cross-laminated timber (CLT) as a priority building material in agency projects. Using CLT in government buildings is one way to confer a public "stamp of approval" to the emerging technology, which could accelerate market demand in other segments of the construction industry.

States and municipalities also have a significant role to play in promoting the growth of the wood products industry. States can establish wood as a preferential building material in their own government buildings or organize a statewide tall wood building competition. Following the example set by the state of Washington in its 2016 Supplemental Capital Budget, states can fund CLT demonstration projects, support in-state CLT manufacturing capacity through technical assistance or other incentives, and study the impacts of changing building codes to allow for greater penetration of wood products. Municipalities can then implement changes to building codes and standards once sufficient research is available and can also commission CLT demonstration projects of their own.

Leveling the Playing Field

The federal government should also ensure that emerging construction materials like CLT can compete on a level playing field with established industries like steel and concrete. This effort may necessitate a review of current subsidies and tax incentives that preferentially benefit certain building materials as well as a review of any restrictions on government-funded construction projects that may limit competition in the sector. Where disparities are found, existing policies should be altered to ensure fair competition among traditional and emerging construction materials or new policies should be enacted to extend the financial and regulatory advantages enjoyed by traditional materials to emerging materials.

ACHIEVING THE MID-CENTURY STRATEGY GOALS

Achieving the MCS GHG emissions reduction goals by 2050 will require significant government investment, collaboration with private and industry partners, and an increase in adoption of climate-smart practices by farmers, landowners, and ranchers. Although current challenges prevent wide-scale adoption of these practices, this paper highlights tangible recommendations for creating a national carbon bank to leverage federal investment in and aggregate practices across working farms, ranches and forests, increasing technical assistance to streamline adoption of best practices at the local level, and strengthening existing agricultural and forestry incentive programs to scale up already successful results.

The benefits generated by government investment in climate-smart practices in agriculture and forestry will reach nearly every state in the country—and the opportunities for local and state engagement are vast. Programs that achieve climate goals while strengthening financial resources available for farmers, ranchers, and forest owners could attract bipartisan support. Furthermore, partnerships with private sector actors, like agribusiness companies and private timber companies, promise to deliver additional economic impact and private sector investment.

Like the goals set forth in the MCS, the recommendations made here are ambitious. A foundation for achieving the goals has already been created by government incentive programs and by growing interest in climate-smart practices and actions among producers, suppliers, landowners, and corporate entities. Farmers and forest owners are beginning to recognize the importance of these practices in ensuring the resilience of their livelihoods and ecosystems, but they need support from the government to implement complex and sometimes expensive practices. Therefore, the government must make strategic investments in agriculture and forestry through a policy framework that comprehensively addresses barriers to action. Only then can real progress in reducing U.S. GHG emissions through the land sector be achieved.

APPENDIX A: METHODOLOGY FOR PRICE DISTRIBUTION OF MITIGATION POTENTIAL

Agriculture

To create a price distribution of mitigation potential for agricultural practices, the analysis presented here used published estimates of practice adoption breakeven prices and mitigation potential obtained from a single report prepared by ICF International on behalf of the USDA (ICF International 2013). The report provided data on current and alternate cropping and livestock waste management practices for each of the following geographical regions of the United States: Appalachia, Corn Belt, Delta, Lake States, Mountain, Northeast, Northern Plains, Pacific, Southeast, Southern Plains. Data for cropping practices were further divided by crop type—corn, wheat, soybeans, cotton, and sorghum—and by starting and ending practice, where applicable. Data for livestock waste management practices were similarly divided by starting practice and final practice as well as by farm type (e.g., dairy, beef, or swine) and farm size (number of livestock).

Three agricultural practices were included in the analysis:

- Conversion from conventional tillage to no-till
- 10% reduction in nitrogen fertilizer application
- Conversion from anaerobic lagoon and deep-pit waste management systems to complete mix anaerobic digesters

The methodology for calculating the aggregate emissions potential available at a given price is described individually for each practice.

Conversion from Conventional Tillage to No-Till

To create a price distribution of cumulative emissions mitigation potential through conversion of conventionally tilled land to no-till land, the analysis used ICF data on breakeven prices (in 2010 $/tCO_2e$), estimated recent adoption levels of tillage practices in the United States (as a percentage of total acreage planted), emissions reduction potential (in tCO_2e per acre), and NASS 2012 Census of Agriculture data on total acreage planted in each crop type in each region.

The following formula was used to determine the aggregate reductions available in each region for each crop type due to this intervention:

$$\text{Reduction Potential } (tCO_2e \text{ per acre}) * \text{Total Acreage (acres)} * \text{Percentage of Total Acreage in Conventional Tillage} = \text{Practice Reduction Potential for X Crop Type in X Region } (tCO_2e)$$

For all regions and crops with costs less than $50/tCO_2e$, the resulting reduction potentials were compiled into a schedule of cumulative potential by cost.

10% Reduction in Nitrogen Fertilizer Application

ICF data on breakeven prices (in 2010 $/tCO_2e$), acres treated with nitrogen (as a percentage of total acreage planted), emissions reduction potential (in tCO_2e per acre), and NASS 2012 Census of Agriculture data on total acreage planted in each crop type in each region were used to create a supply curve of cumulative emissions mitigation potential available from a 10% reduction in the nitrogen fertilizer application rate. For both the breakeven price and the emissions reduction potential, the "High Emissions Reduction Scenario" estimates were used.

The following formula was used to determine the aggregate reductions available in each region for each crop type due to this intervention:

$$\text{Reduction Potential } (tCO_2e \text{ per acre}) * \text{Total Acreage (acres)} * \text{Percentage of Total Acreage Treated with Fertilizer} = \text{Practice Reduction Potential for X Crop Type in X Region } (tCO_2e)$$

For all regions and crops with costs less than $50/tCO_2e$, the resulting reduction potentials were compiled into a schedule of cumulative potential by cost.

Conversion from Anaerobic Lagoon and Deep-Pit Waste Management Systems to Complete Mix Anaerobic Digesters

Estimates of the potential emissions mitigation from improvements in livestock manure management and their associated costs are complicated by the plethora of available technologies and practices through which emissions reductions may be achieved. Practices included in the ICF report include covered lagoon anaerobic digesters; complete mix anaerobic digesters; plug flow anaerobic digesters; pond, tank, and lagoon covers; solids separators; and nitrification/denitrification. The costs and GHG implications of adopting a given system are further affected by the starting waste management practice.

Because it is difficult to predict which practices are most likely to be adopted and in what proportion to other alternatives, this analysis evaluated a single, simplified scenario: the potential reductions achievable from conversion of existing anaerobic lagoons and deep-pit waste management systems to complete mix digesters.

ICF data on breakeven prices (in 2010 \$/tCO_2e), emissions reduction potential for farms by size (in tCO_2e per farm), and number of farms of a given size per region as well as EPA data on the percentage of farms that utilize specific waste management systems were used to create a supply curve of cumulative emissions mitigation potential available from installing complete mix digesters on existing anaerobic lagoon and deep pit systems (U.S. EPA 2004).

The following formula was used to determine the aggregate reductions available in each region for each farm type and size due to this intervention:

Reduction Potential (tCO_2e per farm) * Total Number of Farms * Percentage of Farms That Utilize X Starting Waste Management System = Practice Reduction Potential for X Farm Type of X Size in X Region (tCO_2e)

For all regions and crops with costs less than \$50/tCO_2e, the resulting reduction potentials were compiled into a schedule of cumulative potential by cost.

Forestry

To create a price distribution of mitigation potential for forestry practices, peer-reviewed studies were surveyed for estimates of the mitigation potential from forest carbon sequestration practices that would be economically feasible at various carbon prices. Such estimates were available for improved forest management (IFM) from seven studies and for forest expansion from six studies. For each study, the analysis plotted the mitigation potential of each practice in million metric tons of carbon dioxide equivalent (MMT CO_2e) against the carbon price in dollars per metric ton (\$/tCO_2e) at which that potential would be economically feasible. For each study, a best-fit regression line was calculated to represent the supply curve of mitigation potential in each practice (figures A.1–A.2).

Using equations for the best-fit regressions for each study, the analysis calculated the mitigation potential that would be predicted by each study at a series of carbon prices between \$5 and \$50/tCO_2e. At each carbon price, this potential was calculated only for studies that covered that price point in their analysis—that is, if a study reported mitigation potential at \$25 and \$50/tCO_2e, the analysis presented here would calculate the predicted mitigation potential for \$30/tCO_2e (which is within the range of analysis) but not for \$10/tCO_2e (which is outside the range). Finally, the predicted mitigation potentials were averaged for all relevant studies at each carbon price to determine the price distribution of mitigation potential in forestry.

Figure A.1. Best-fit regressions for study estimates of IFM potential at various carbon prices

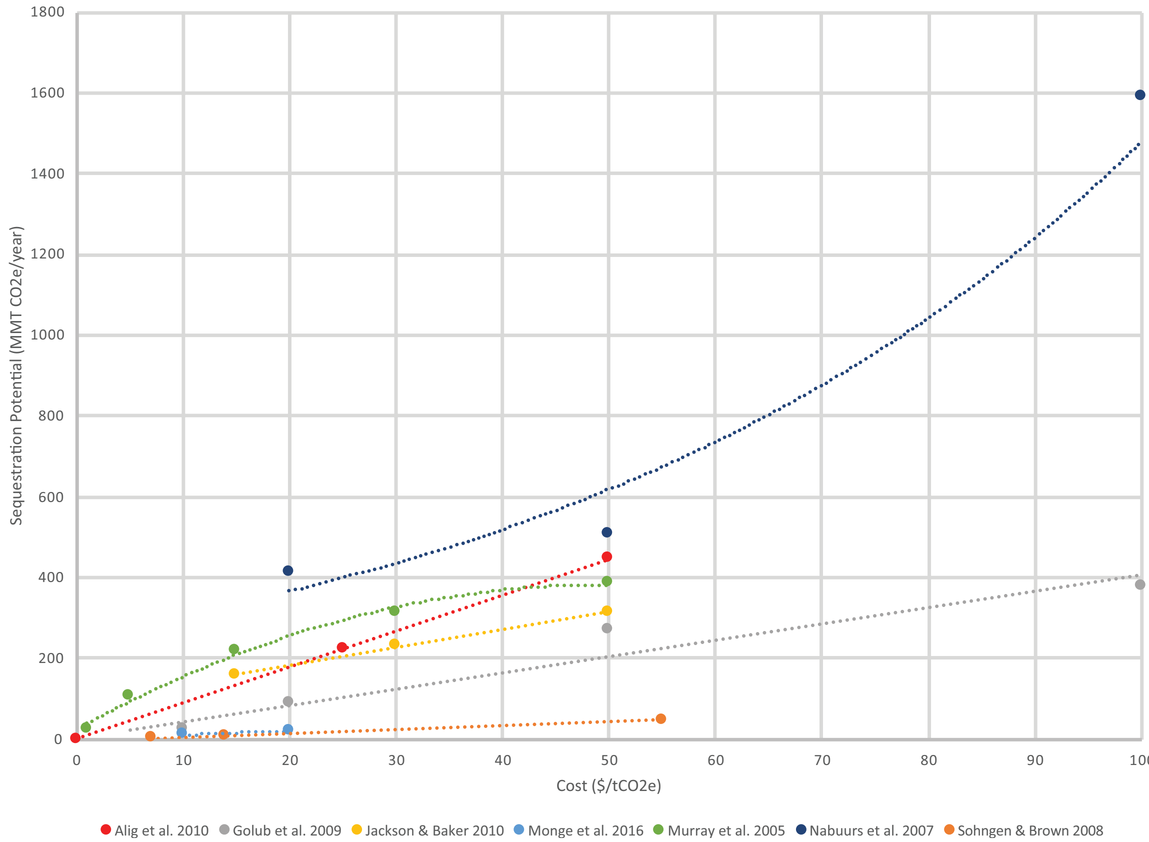
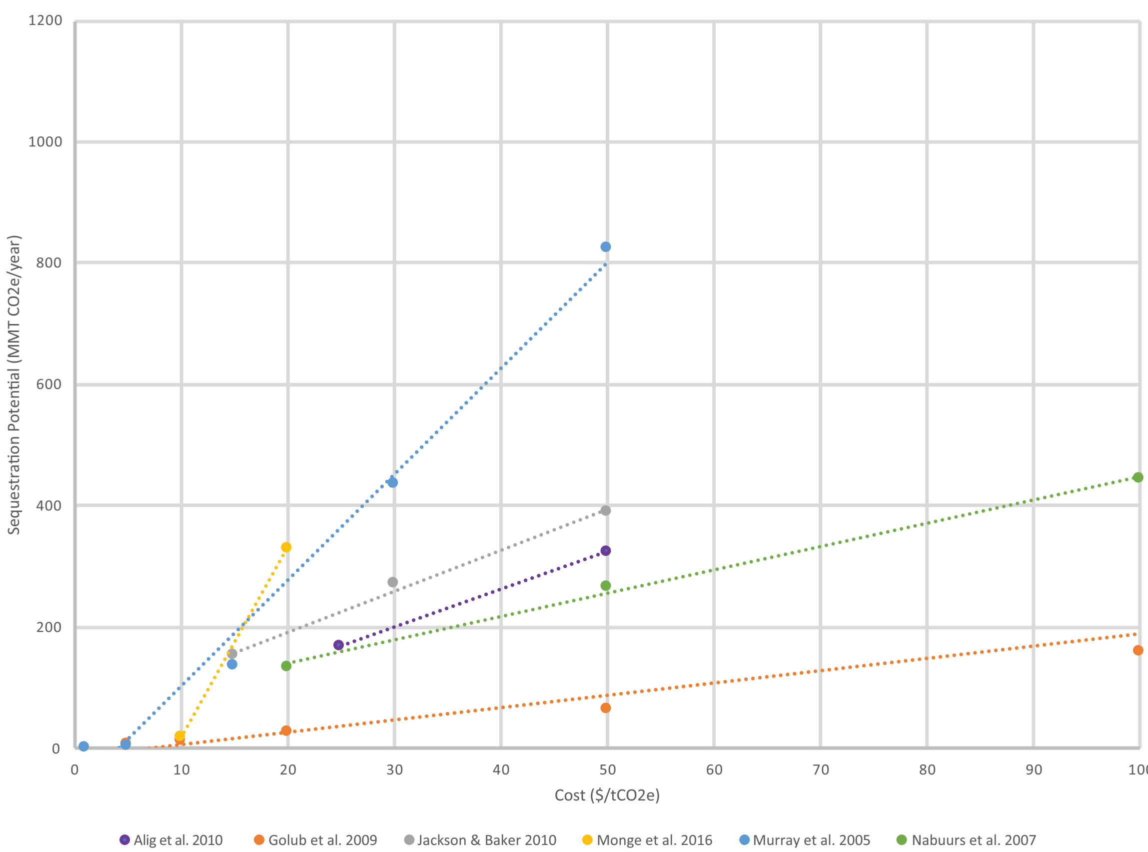


Figure A.2.



APPENDIX B: METHODOLOGY FOR GEOGRAPHY OF MITIGATION POTENTIAL

Practices Considered

Under the MCS framework, the geospatial analysis presented here focused on the following practices:

Forests

- Reducing the risk of carbon emissions from wildfire through improved forest management (IFM) on public forestlands
- Increasing carbon sequestration through IFM on private forestlands
- Avoiding carbon emissions from forest conversion or loss on private forestlands
- Forest expansion through reforestation on private lands.

Agriculture

- Reducing soil carbon release through conservation tillage techniques on corn, wheat, soy, and sorghum cropland
- Protecting soil carbon in pasturelands
- Managing nitrous oxide emissions by reducing excessive or untimely nitrogen fertilizer applications
- Managing methane emissions by managing manure and installing methane digesters on dairy, beef, and pig farms.

Study Area

This paper's policy recommendations will apply nationwide, so the geospatial analysis also covered the entire country. However, that analysis was limited to the conterminous states due to limited data availability for Alaska, Hawaii, and U.S. territories.

Analysis Methods

The analysis was conducted in ArcGIS Pro (Esri 2018) using two sets of data: one for forests and another for agriculture (Table B.1). Each data input was standardized to a 240-m raster of the conterminous United States using the USA Contiguous Albers Equal Area Conic USGS version as the projected coordinate system. To determine whether or not each pixel represented a potential threat or opportunity for carbon sequestration in forests and agriculture, the analysis used thresholds identified from the literature or input metadata to create binary rasters for each data input. Any pixels meeting or exceeding these inclusion thresholds were given a value of 1, and all others were given a value of 0 unless otherwise noted.

Table B.1. Data inputs

Category	Data source	Key attribute	Inclusion threshold
Forests	National Land Cover Database[a]	Current location of forest in the United States	Cover types 41, 42, 43, 90 (forests and woody wetlands)
	National Biomass and Carbon Dataset[b]	Carbon content of forest areas	Low carbon: <50 $mtCO_2e/ac$ High carbon: >50 $mtCO_2e/ac$[c]
	Forest loss, 2000–2016[d]	Risk of forest conversion	Forest loss in any year
	U.S. forest ownership[e]	Forest ownership	Public or private[f]
	Wildfire hazard potential[g]	Risk of wildfire	Moderate, high, or very high wildfire potential
Agriculture	Cropland data layer[h]	Current location of key crops in the United States	Corn, wheat, soy, and sorghum cropland[i]
	Head of livestock by county[j]	Current location of key livestock production in the United States	Counties with >500 head of dairy or beef cattle or hogs[k]
	Nitrogen fertilizer application in North America[l]	Areas of high nitrogen fertilizer use	Fertilizer applications >15 lbs nitrogen/ac/yr[m]
	Acres of farmland by county; Proportion of farmland in pasture[n]	Current location of pastureland in the United States	Counties with >30% pastureland by area
	U.S. county boundaries[o]	Allows county-level data to be spatially represented	

[a] Homer et al. (2015).
[b] Kellndorfer et al. (2012).
[c] Birdsey (1992); kept as 2 classes, not binary
[d] Hansen et al. (2013).
[e] Hewes et al. (2014).
[f] Ibid; kept as 2 separate classes, not binary
[g] Dillon (2015).
[h] NASS (2016).
[i] ICF International (2013).
[j] NASS (2012).
[k] ICF International (2013).
[l] Potter et al. (2011).
[m] ICF International (2013).
[n] NASS (2012).
[o] U.S. Census Bureau (2017).

For both the forest and agriculture categories, the binary rasters of each attribute above were combined into one file and Boolean logic arguments were used to isolate pixels meeting the criteria for each considered practice (Table B.2). With these pixels identified, maps for each category were created to represent the spatial distribution of each practice for forests and agriculture, and the datasets were combined into one map to represent the potential for practices across the country.

Table B.2. Criteria for targeted practices

Category	Practice	Criteria
Forests	IFM: public forestlands	• Publicly owned forest • Risk of wildfire
	IFM: private forestlands	• Privately owned forest • Forest cover present • Low carbon stocks
	Forest expansion: private lands	• Privately owned land • Recent loss of forest • Forest cover present (historically)
	Avoided conversion	• Privately owned forest • Recent loss of forest nearby • High carbon stocks
Agriculture	Conservation tillage (no-till) on corn, wheat, soy, and sorghum cropland	• Corn, wheat, soy, or sorghum cropland present
	Protecting soil carbon: pasturelands	• Pastureland present
	Nitrogen fertilizer reduction	• High nitrogen fertilizer use
	Livestock manure management	• Livestock production present

Assumptions and Limitations

Several assumptions underlay this analysis. Because the data were collected in different years by various agencies, they were taken to be the most accurate and recent representations of each key attribute of our analysis. The methodology, especially the inclusion thresholds listed in Table B.1., was necessarily simple to facilitate an analysis on a nation-wide scale. The generalization necessary to apply a single threshold across the entire country will undoubtedly have overlooked more localized nuances or patterns in the data, but this generalization is an acceptable given the analysis's objectives.

This analysis was somewhat limited by data, both in availability and in the time required to process the quantity of data on a national scale in raster form. For this reason, the analysis rescaled the data to 240-m pixels, though half of the datasets were originally in a 30-m format. On a nationwide level, this loss of detail was acceptable, because the 240-m rasters still provided ample information. However, for policy implementation on the ground, more detailed and fine-scale data may be beneficial despite the extra required processing time. Additionally, some datasets were incomplete, most notably the NASS Census of Agriculture data for head of livestock and acres of pasture/farmland by county. Some counties, to protect the privacy of their farmers and ranchers, did not disclose explicit numbers for agricultural production, instead opting to indicate simply whether or not a commodity was produced there. Without a discrete number for pastureland acreage or head of livestock, it is unclear whether these counties would meet or exceed inclusion thresholds listed in Table B.1. Consequently, these counties were excluded from our analysis.

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