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Building Carbon in America's Farms, Forests, and Grasslands: Foundations for a Policy Roadmap

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Building Carbon in America's Farms, Forests, and Grasslands: Foundations for a Policy Roadmap

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Table of Contents

Foreword

With ink barely dry on the Paris Agreement, agreed by nearly 200 countries after decades of debate and political inertia, some have said we are now on an inevitable path towards a global low-carbon economy. To be sure, we now have the opportunity, and the obligation, to take decisive action. Floating behind a screen of complexity is a critical piece of this low-carbon puzzle – land. Land can be a carbon source or a carbon sink – sequestering CO_2 in trees, soils, and long-lived products, or releasing emissions through wildfires, decay, and conversion of natural landscapes to urban areas and cropland. How we manage global landscapes can make all the difference in whether land will help or hinder our battle against climate change.

In the United States, where this report focuses, we have been sequestering significant amounts of carbon in forests, grasslands, and soils, enough to offset roughly 15 percent of all fossil fuel-related emissions each year over the past several decades, an amount equal to more than half of all transportation emissions. Our growing forests and strong conservation programs have played an important role in this sustained achievement. The question is – will this carbon sink continue to support our climate goals?

The future is cloudy. The latest U.S. assessments disagree on whether land will be a sink or a source in the coming decades. Despite significant research, a complete understanding of policy or market tools capable of bending the trajectory of carbon storage one way or the other remains elusive. In practice, there are no guidelines for how to manage for carbon sequestration on federal lands. There are virtually no federal incentive programs that prioritize land carbon sequestration on private lands. And while 90 companies account for two thirds of global historic fossil fuel emissions, the top 100 U.S. landowners manage only 2 percent of the landscape – a formidable challenge for coordinating carbon sequestration efforts.

These challenges have not gone unnoticed. The Obama Administration has taken important initial steps to improve land carbon inventory programs. Through their "10 Building Blocks" announced in 2015, the USDA is bolstering programs under their purview to leverage more carbon sequestration. States like California have taken notice, setting aside over $100 million of cap-and-trade revenue for land carbon, as have the private sector, foundations, and non-profits. But even with these critical initial steps, existing policies, programs, and markets cannot guarantee the land carbon sink in the coming decades.

The Land Carbon Policy Roadmap initiative was launched to address these continued challenges and uncertainties head on, bringing together an unprecedented group of actors across forestry and agricultural sectors, academics, government officials, and environmental stakeholders to develop a plan for systematically growing the U.S. carbon sink. It was launched to heed Paris' call to action and to lay the groundwork for those efforts. This report is the first step in that process.

In the pages that follow, the report points to immediate priorities for action. Creating guidance for carbon management on federal land will ensure carbon sequestration is a priority on half of all U.S. lands. Creating value for carbon management through tax incentives, market-based crediting programs, and updated conservation programs can reward private landowners for their emissions reduction efforts. New policy frameworks can encourage protection of carbon-rich landscapes, adding carbon to the list of resources cared for and stewarded by American land owners and managers, like wetlands and species habitat.

Supporting these priorities are a number of other research, policy, and implementation recommendations that, together, outline a plan for action. While in the past we may have suffered from imperfect certainty, this is no longer the case. As this report illustrates we have enough information to act now. It is from this perspective that the Land Carbon Policy Roadmap begins to assess and refine our possible policy futures, shows how these ideas can support work with a diverse coalition of stakeholders around the country, and ultimately crystallizes a vision for healthy, high-carbon landscapes across the United States.

Michael Jenkins
Founding President and CEO
Forest Trends

Executive Summary

The vegetation and soils found in landscapes across the United States serve as carbon sinks, removing an estimated 850 million metric tons of CO_2-equivalent (CO_2e) from the atmosphere each year and offsetting 16 percent of annual industrial emissions. There is significant uncertainty about the future and scale of this sink. Failure to stabilize the current sink and preserve U.S. land carbon mitigation capacity could jeopardize the effectiveness of U.S. climate change policy and the nation's ability to meet future emissions reduction targets.

To address this challenge, a consortium of organizations and experts came together to launch the Land Carbon Policy Roadmap (LCPR) initiative to develop and implement policy recommendations that ensure U.S. lands continue to significantly reduce economy-wide emissions through 2050 and to provide robust agricultural, silvicultural, and ecosystem services. This report is the first step toward developing that roadmap.

The review below focuses on major drivers of land carbon change in the United States and the plethora of existing programs and policies that impact it. Initial findings from a quantitative review of the most significant land-use and land management drivers of carbon flux and the existing policies that influence them indicate that this information is not presented uniformly across the literature and across U.S. regions, limiting decision makers' abilities to prioritize policy initiatives. Nonetheless, there are a number of areas where this analysis indicates early action is warranted as a longer-term roadmap is developed.

A suite of recommendations for additional analysis and policy consideration is captured here for further exploration in subsequent phases of the LCPR initiative, focusing on: ways to improve availability and quality of information to support policy deliberation; options for addressing gaps in the existing policy landscape; and priorities for immediate action. Building on the recommendations below, the next phase of this initiative will undertake original quantitative analysis to support policy roadmap development and define policy recommendations through extensive regional stakeholder engagement and demonstration project assessments.

Decision-Support Recommendations

The following recommendations seek to address gaps in data and information to support informed decision making and policy development for land carbon management.

- **Organize land carbon data in a way that is more useful to decision makers.** Organizing data according to the drivers affecting change can better guide policy development and support policy impact assessments.
- **Undertake updated and expanded analysis of mitigation potential utilizing consistent accounting approaches.** More information is needed to support decision makers' understanding of the net potential impact of the suite of policy recommendations discussed in this report. Assessments of different land carbon interventions could be explored through a research consortium or U.S. interagency process that the research community can adopt and implement.
- **Support research and data collection to better understand Alaska's land carbon trajectory.** Failure to include Alaska's vast boreal forest and wetlands in the national carbon balance could significantly affect prospects for success in maintaining the carbon sink, either positively or negatively. This is a large wildcard in climate target decision making.

Policy Recommendations

This report assesses existing U.S. policies and programs, key drivers of changes in land carbon, and identifies policy levers that could enhance land carbon sequestration potential. The policy recommendations fall into three overarching categories:

- **Plan** to maximize carbon benefits of federal decision making, employing robust frameworks for assessing impacts of activities, policies, and programs to address land carbon across agencies.
- **Optimize** the carbon benefits of existing conservation and incentive programs, incorporating land carbon into funding allocation decisions.
- **Leverage** private capital through development of new regulatory frameworks, primarily mitigation banking and other market-based approaches.

These recommendations build on some previously advocated by stakeholders. The goal was to comprehensively aggregate major policy interventions and assess their relative merits to guide priority setting on the basis of mitigation potential, political feasibility, cost, and other considerations. However, an exhaustive literature review demonstrated the difficulty of generating firm conclusions that could guide immediate policy action. Further analysis and stakeholder engagement would provide greater insight into each policy's potential and feasibility.

Plan

- **Elevate the integration of carbon into federal land planning.** Additional steps could be taken to encourage scientifically robust strategies to better integrate carbon storage as one land management priority on federal lands (e.g., through the U.S. Forest Service's Land Management Planning Rule).
- **Offer federal incentives for high-carbon intensity zoning.** Zoning ordinances are a significant driver of development patterns. A federal incentive could be implemented for communities that develop easement programs or zoning ordinances that protect high-carbon landscapes.
- **Integrate land carbon into the Executive Order for Sustainability.** The Executive Order for Sustainability or a new executive order could promote integration of carbon optimization into federal land management plans.

Optimize

- **Integrate carbon into conservation program funding priorities.** Many federal conservation programs already, or have the potential to, generate land carbon sequestration benefits, though most do not consider carbon sequestration a priority when allocating funding.
- **Expand geographic coverage of Sodsaver and similar programs.** Many environmental and sustainable agriculture groups suggest that the Sodsaver provision of the 2014 Farm Bill could be expanded to apply to additional prairie states. Similar programs could be designed to preserve other high-carbon landscapes vis a vis crop insurance and other agricultural support programs.
- **Incorporate climate considerations into agricultural support programs.** Agencies could account for potential climate impacts when implementing crop support programs, incentivizing practices that minimize greenhouse gas (GHG) emissions and loss of land carbon.
- **Develop tax incentives based on forest carbon.** Currently, forest owners receive certain tax benefits that create value for keeping land as forest and tree planting. Additional tax deductions or credits could be put in place for forest owners who participate in activities that yield carbon benefits.
- **Integrate land carbon as a consideration in federal rural development and agricultural incentive programs.** Biomass, bioenergy, and wood products market support programs could more explicitly recognize land carbon enhancement as a priority when making funding decisions.

Leverage

- **Develop regulatory models that catalyze private finance for conservation.** Federal conservation funding is declining, likely limiting the reach of federal programming in achieving additional GHG mitigation. Leveraging private sector finance through environmental markets and direct investment will be necessary to maximize land carbon response. For these markets to be truly scalable, new policy at the state or federal level may be necessary.

- **Protect high-carbon landscapes.** High-carbon landscapes could be protected through "no-net-carbon-loss" policy frameworks. New policy could require that any impacts on these areas be offset through restoration, enhancement, or creation of high-carbon landscapes in the same region, potentially leveraging recent White House guidance on mitigation banking as a preferred strategy for protecting and managing natural resources.
- **Reduce the risk of participating in carbon-offset programs for landowners.** Both California and Regional Greenhouse Gas Initiative (RGGI) programs have strict requirements for 100-year monitoring and require the offset generator to bear the risk of carbon sequestration reversals over the project period. One opportunity for enhancing the attractiveness of offset programs is to create more flexible approaches for managing the risk of carbon loss or reversal, such as federal insurance or revenue-risk-reduction programs.
- **Increase the number of opportunities for crediting of carbon-beneficial activities.** A variety of activities with the potential to increase land carbon storage are not currently covered by compliance-grade offset protocols. Rather than develop protocols for these activities, revenues from cap-and-trade or other programs (such as the Clean Power Plan) could be recycled to support additional land sector mitigation on a practice or area basis.
- **Build the investment case for Agriculture, Forestry, and Other Land-Use (AFOLU) Bonds.** Climate and green bonds could be useful mechanisms for financing land carbon projects and projects that indirectly enhance land carbon, if markets are working. Supporting new project development that can utilize climate finance tools could stimulate a pipeline of land carbon projects.

Priorities for Immediate Action

Developing a holistic land carbon policy strategy on the basis of available data is difficult, but several key areas identified in this analysis could warrant immediate action. Regional demonstrations in these areas could support near-term learning and stakeholder engagement to develop workable regulatory and investment models. These target areas include the following:

- **Optimize patchwork of existing federal programs to support land carbon.** As this report illustrates, many existing federal levers could be tailored to drive positive land carbon outcomes. A regional project, for example, through the Regional Conservation Partnership Program (RCPP), could assess the potential for integrated carbon management through a variety of federal programs. The objectives would be to demonstrate existing programs' capacity to generate carbon sequestration and to support a more rigorous theoretical process for achieving cross-cutting land carbon outcomes with existing federal resources.
- **Develop forest management principles and guidance for optimizing land carbon with other management priorities.** Forest management can have significant implications for the carbon sink. The impacts of a number of factors, including harvested wood products, fossil fuel offsets, wildfire risk reduction, and indirect/market effects of reduced or increased forest removals should be assessed and integrated into sustainable forest management frameworks. Additional analysis would support full understanding of the potential impacts of any policy action for forest management and changes in carbon stock.
- **Incentivize forest regeneration and afforestation.** Understanding the additional mitigation potential of afforestation and regeneration, particularly in counteracting the effect of aging forests throughout the United States, and putting in place new policies to incentivize these activities could address a significant gap.
- **Reduce risk of forest conversion to settlement.** Currently, no federal policy drivers, specifically or directly, limit forest conversion to settlement. Several policy priorities identified above, including new "no-net-loss" policies for forests and high carbon-intensity zoning, could help address this gap. Incremental incentive programs could have some impact but are unlikely to overcome the high value of forest-to-settlement conversion.

These immediate priorities could be implemented through regional demonstrations and individual project development in 2016 and could be scaled up regionally and nationally thereafter.

Next Steps

Based on this set of recommendations, the LCPR initiative proposes the following next steps, with the ultimate goal being development of a long-term policy roadmap for maintaining and enhancing U.S. land carbon sequestration:

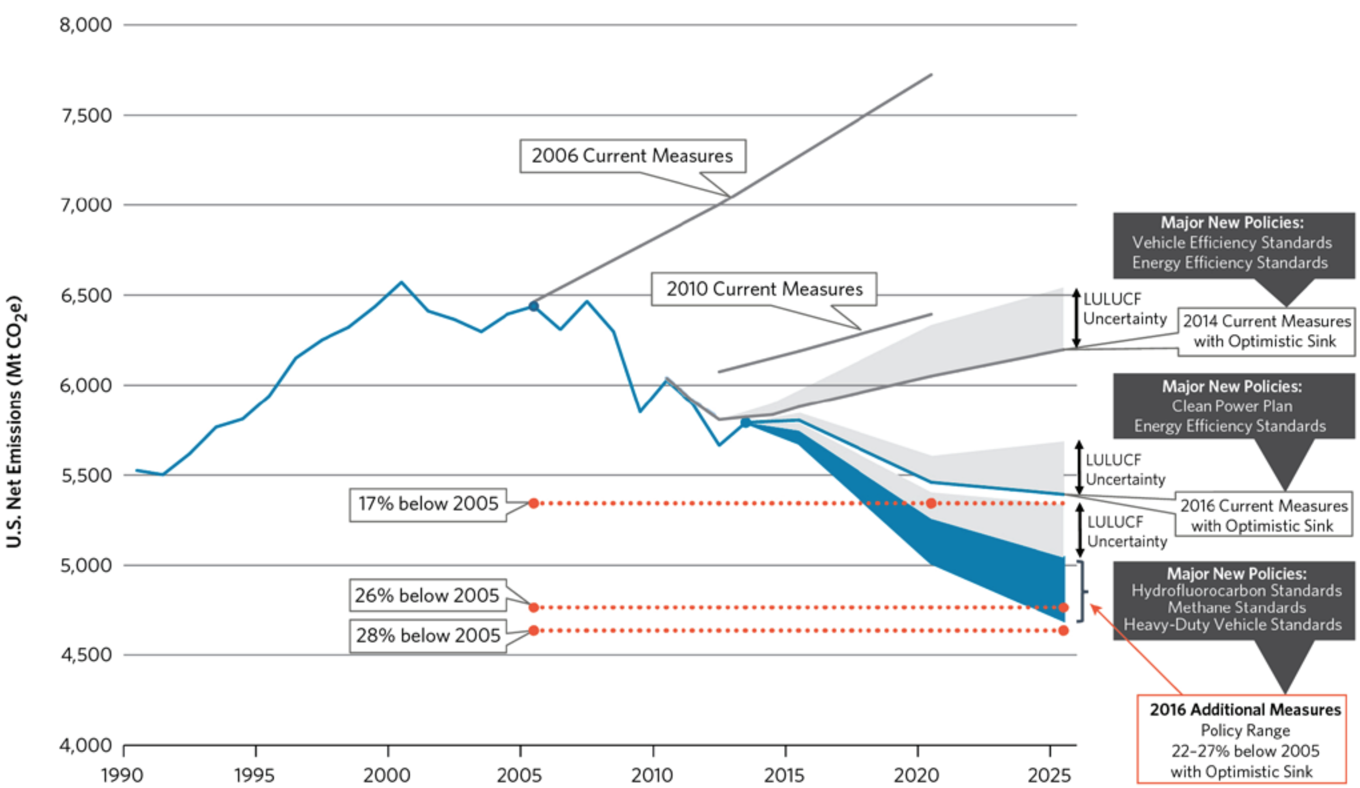
- **Develop and regionally demonstrate immediate action priorities.** Leveraging existing projects and programs where possible, regional demonstrations or pilots of key policy recommendations can improve understanding of policy impacts, scalability, and feasibility. Demonstrations – executed in cooperation with landowners, local policy makers, environmental stakeholders, and others – would be designed to address regionally specific land carbon drivers and priorities. Private sector investment approaches would be highest priority for pilot demonstrations, in order to counteract declining federal conservation funding and achieve significant national scale.
- **Develop holistic analytical framework.** Historically, projections of future mitigation potential have been conducted in a piecemeal fashion, providing critical information about the performance of specific programs or practices but not about the interactions of a complex array of separate initiatives such as those discussed here. Building on existing data and analysis, a robust analytical framework accounting for direct and indirect impacts and interactions of a full suite of land carbon policies can help to identify the policy interventions necessary to maintain and possibly enlarge the carbon sink.
- **Further develop and streamline policy priorities.** Building on additional analysis and improved understanding of total mitigation potential, the initiative would work with stakeholders, experts, and policy makers to further refine policy priorities.
- **Detail policy design.** On the basis of stakeholder, expert, and policy maker consultations, the initiative would determine key policy design considerations. This process will support assessment of mitigation potential through the updated analytical framework. Private sector and investment community engagement would be top priority in order to complement limited government resources and achieve the largest scale of impact possible.
- **Execute engagement to implement preferred policies.** Once priority policies are chosen and policy design is elaborated, stakeholders can execute outreach to implement new policies.

1. U.S. Land Carbon Stock and Its Role in Achieving Long-Term Climate Goals

The President Obama's Climate Action Plan has advanced important initiatives for meeting the 2020 U.S. climate target, addressing emissions from coal plants, vehicles, appliances, and buildings. But additional efforts, particularly in the land sector, will be needed to meet climate targets in 2020 and beyond. Forests, grasslands, croplands, wetlands, and even urban landscapes remove about 850 million metric tons of CO_2e from the atmosphere each year, offsetting approximately 16 percent of annual emissions (U.S. Environmental Protection Agency 2015). Industrial and transport sectors comprise 90 percent of U.S. greenhouse gas (GHG) emissions; land use, land-use change, and forestry-related emissions contribute the most uncertainty to U.S. climate objectives.

Figure 1 shows projections of U.S. GHG emissions to 2025 based on analysis in the *Second Biennial Report of the United States of America* ("BR2"). The BR2 represents the official position of the U.S. government with regard to its commitments under the UN Framework Convention on Climate Change (UNFCCC) (U.S. Department of State 2015). It contains the most recent and complete presentation of U.S. historical and projected land carbon sink values. As the BR2 shows, the land carbon sector in future years is subject to uncertainty (shown as "Land Use, Land-Use Change, and Forestry (LULUCF) Uncertainty"), and could play an important role in determining whether future U.S. goals are met.

Figure 1. U.S. Emissions Projections to 2025



Source: U.S. Department of State (2015).

The BR2 contains a range of LULUCF projections. Higher projections of land carbon are based on Environmental Protection Agency (EPA) analysis, and are driven largely by positive feedbacks between forest products markets and investment in private forests, yielding a more robust carbon sink over the coming decades. The lower projections of land carbon sequestration are based on U.S. Department of Agriculture (USDA) and U.S. Forest Service (USFS) analysis that are driven by high population growth and related land-use conversion away from forests to urban use, resulting in a decline in the forest carbon sink over time.

The range in estimates and the strong influence of the multiple drivers that underlie them demonstrates the importance of better understanding how both new and existing policies and markets affect the U.S. carbon sink. Against the backdrop of these complex policy and market drivers is the practical reality that private and public land-based carbon is not currently managed holistically under any government scheme (Im et al. 2007), while private sector approaches, such as land carbon offsets, are being implemented but at relatively small scales.

There is also the possibility that U.S. forests and other landscapes may be reaching a new equilibrium state. Following many decades of forest regrowth, afforestation, and soil conservation efforts, U.S. land may be headed toward a steady state of carbon sequestration or even becoming a net carbon source (U.S. Environmental Protection Agency 2015). A "steady state" would mean that the yearly change in carbon stock, or the carbon flux, would hover around zero. The annual carbon sink is only a small fraction of overall land carbon stock, or the total carbon stored in land. Importantly, the only way to maintain or increase the carbon sink is to ensure the current annual rate of carbon sequestration does not decline.

These dynamics contribute to the future uncertainty of the U.S. carbon sink and suggest the need for new policy frameworks. Recognizing this need, U.S. government agencies and others are taking important steps to reduce uncertainty and to implement supportive policies and programs. In April 2015, the U.S. Department of Agriculture (USDA) announced "10 Building Blocks" for increasing land carbon and reducing emissions by 120 million metric tons of CO_2 per year by 2025 (U.S. Department of Agriculture 2015f). The building blocks are based on existing USDA programs and authorities. USDA, the Environmental Protection Agency (EPA), the Department of Interior (DOI), and others are also working to enhance land carbon data collection, inventorying, and modeling to improve the LULUCF inventory and develop more consistent inputs to the U.S. Biennial Report. In December 2015, the White House released a report summarizing these critical inventory improvements, including better integration of data across agencies to track emissions from changes in land management and use, updating forest carbon accounting methods (described in detail in Woodall et al. 2015), and expanding plot survey data across a variety of landscapes and activities (The White House 2015a). These improvements are critical for addressing some of the data challenges discussed below.

To build on these important first steps, in 2015 several environmental organizations identified the need to develop a long-term, strategic policy roadmap for sustaining the U.S. carbon sink, launching the Land Carbon Policy Roadmap (LCPR) initiative. The LCPR seeks to compile a set of robust policy recommendations underpinned by the latest and most comprehensive research that ensures the land carbon sink continues to significantly reduce economy-wide emissions in the coming decades while supporting robust agricultural, silvicultural, and ecosystem services on public and private lands.

This report is the LCPR initiative's first deliverable. It seeks to provide all necessary foundational information for understanding the key drivers of land carbon gain and loss in the United States, the potential gain/loss trajectory to 2050, and initial recommendations for priority policy interventions. It also seeks to clearly identify questions to be answered in order to develop a policy roadmap and to determine the need for additional analytics, planning, outreach, and policy assessment work, thereby providing a springboard for the initiative's implementation in 2016–2017.

The report has been influenced by input from a panel (see Acknowledgements) reflecting ecological, economic, modeling, and policy expertise. This input supported compilation and synthesis of the existing literature, which is extensive, dense, and at times contradictory.

To decrease the complexity and uncertainty of the analysis, the report does not consider non-CO_2 emissions such as nitrogen oxide and methane, which can significantly affect emissions accounting for land management practices. The report's scope is limited to interventions that would enhance CO_2 sequestration, either through an increase in carbon storage or a reduction of carbon loss. Any further development of policy would entail consideration of tradeoffs among greenhouse gases. Furthermore, the analysis covers only those emissions sources and sinks included in the LULUCF chapter of the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. Environmental Protection Agency, 2015).

Accordingly, this report:

- Provides an overview of the U.S. carbon sink (Section 2), paying particular attention to the drivers of emissions and sequestration;
- Discusses U.S. land carbon projections (Section 3), emphasizing areas of agreement and uncertainty;
- Presents an overview of mitigation options (Section 4), leveraging the available literature to assess interventions that are feasible as well as achievable;
- Reviews existing policies and programs that have some effect on the U.S. land carbon sink (Section 5), providing the basis for identifying areas of potential policy or practice need;
- Reviews mitigation options (Section 6), providing insight into the feasibility of selected strategies, and discusses other issues that could complicate implementation;
- Describes potential next steps in Section 7.

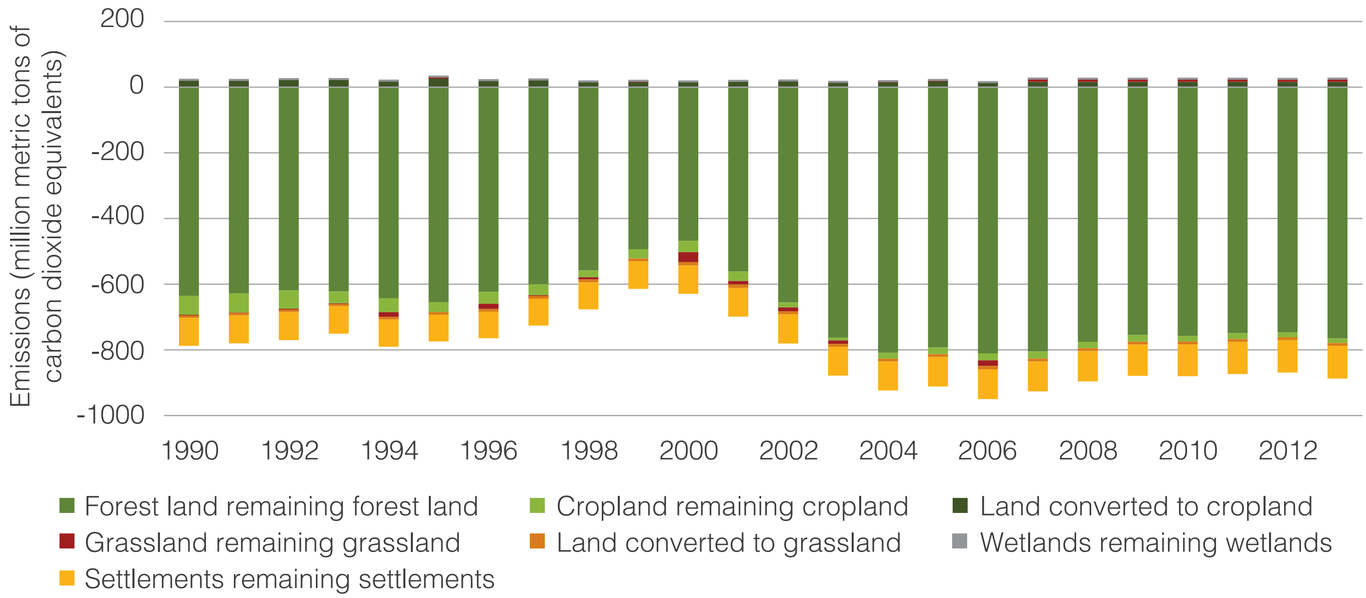
2. Overview of the U.S. Carbon Sink

This analysis discusses the components of U.S. lands and land management covered in the "land use, land-use change, and forestry (LULUCF)" chapter of the Inventory of U.S. Greenhouse Gas Emissions and Sinks – hereafter, the U.S. GHG Inventory. It begins with a review of past U.S. land carbon dynamics according to the U.S. GHG Inventory (2015) and an examination of the drivers of past carbon changes to understand how they might affect the future carbon sink.

2.1. How Is the Landscape Changing?

Across LULUCF categories, carbon sequestration rose approximately 13.6 percent between 1990 and 2013. The net increase in the rate of carbon accumulation in forest carbon stocks was the primary driver of this change (Figure 2).

Figure 2. U.S. Greenhouse Gas Emissions from Land Use, Land-Use Change, and Forestry (1990–2013)



Source: U.S. Environmental Protection Agency (2015).
Note: Though their emissions have decreased, wetlands remaining wetlands and land converted to cropland remain emissions sources.

Two other notable changes in the U.S. landscape from 1990 to 2013 were a 31 percent increase in settlements and a 6 percent reduction in cropland (Table 1).

Table 1. Managed and Unmanaged Land Area by Land-Use Categories for All 50 States

Land-Use Category	1990 (Thousands of Hectares)	2013 (Thousands of Hectares)	% Change
Forest Land	298,598	302,386	1.3%
Croplands	170,448	159,230	-6.6%
Grasslands	350,109	346,430	-1.1%
Settlements	38,602	50,614	31.1%
Wetlands	44,453	43,025	-3.2%
Other Land	34,021	34,545	1.5%

Source: U.S. Environmental Protection Agency (2015).

2.2. Key Drivers of Land Carbon Change

To identify the largest and highest-priority policy interventions, the various drivers of land-use and land management change can be quantified in terms of affected national and regional acreage and estimated carbon flux. To complete this analysis, we performed a literature review on the primary drivers of land carbon change on landscapes. Primary drivers are defined here as any causes of changes in land carbon stock that entailed direct changes in land management, land use, or both as well as major natural drivers (e.g., drought, weather, atmospheric CO_2 levels).

The literature review presented in Table 2 and Table 3 includes estimates of either regional or national total carbon change that could be attributed to one or more discrete drivers, particularly those reflecting the fewest conflating drivers. For example, estimates of carbon gained from forest growth would reflect net primary productivity, before removals. In some cases, no estimates for primary drivers were found (indicated in the tables by "No data available"). In other cases, some quantitative estimates were available or could have been calculated but uncertainty was high (indicated in the tables by "Significant uncertainty").

The numbers in Tables 2 and 3 could not be summed to find total impact because there is duplication of national and regional estimates and because it is impossible to ensure that some estimates do not reflect the impacts of other drivers. Nevertheless, the analysis roughly indicates the scale of each driver's impacts at the national and, where data are available, at the regional level.

The literature on various drivers of land-use change rarely translates the change into carbon loss or gain at a regional or national scale (Nunery and Keeton 2010; Turner et al. 2011). This lack of quantification presented the greatest challenge to the carbon sink analysis. Moreover, fewer papers are dedicated to quantifying current contributors to land carbon than are dedicated to projections of total mitigation potential (McKinley et al. 2011; Nave et al. 2013; Birdsey et al. 2014)

Table 2. Land Management and Land-Use Change Drivers Contributing to Decreased Carbon Storage

Region	Land-Use Category and Ownership	Drivers	Land Area	Indicative Annual Flux (MMT CO_2e)
National	**Settlements**	Conversion to settlement	No data available	No data available
Pacific Northwest (Seattle only)[a]	**Settlements**	Conversion to settlement	0.04	-0.4
Southeast[b]	**Settlements**	Conversion to settlement	0.4	-76.1
National[c]	**Forest, public, private**	Removals	No data available	-646.1 to -337.3
Southeast[d]	**Forest, public, private**	Removals	5.4	-281.2
National[e]	**Forest, public, private**	Cropland conversion – soil carbon	0.6	-0.5
Southeast[f]	**Forest, public, private**	Cropland conversion – soil and above ground carbon	0.3	-48.1
National[g]	**Forest, public, private**	Wildfire	9.4	-77.9 to -209
Southeast[h]	**Forest, public, private**	Wildfire	1.1	No data available
National[i]	**Forest, public, private**	Insect and disease	4.7	No data available
Southeast[j]	**Forest, public, private**	Insect and Disease	0.4	No data available
National[k]	**Forest, public, private**	Drought	0.06	No data available
Southeast[l]	**Forest, public, private**	Drought/weather	1.1	No data available
National[m]	**Forest, public, private**	Forest aging	No data available	Significant uncertainty

Region	Land-Use Category + Ownership	Drivers	Land Area	Indicative Annual Flux (MMT CO_2e)
National[n]	**Cropland, private**	Conventional tillage	239	Significant uncertainty
National[p]	**Cropland, private**	Organic soils for crop production	2	-22.1
National[q]	**Cropland, private**	Grassland Conversion to Cropland	37.8	-16.1
National[r]	**Cropland, private**	Summer fallow	49	No data available
Corn Belt, Northern Plains[s]	**Cropland, private**	Corn-soy rotation	27.2	No data available
National[t]	**Grassland, private**	Drought	606.6	-12.1
National[u]	**Grassland, public**	Drought	185.3	No data available
All Western regions[v]	**Grassland, private, public**	Grazing intensity, rangeland	560.7	Significant uncertainty
National[w]	**Grassland, private, public**	Grazing intensity, pastureland	103.7	Significant uncertainty
National[x]	**Wetlands**	Silviculture	0.06	-0.04
National[y]	**Wetlands**	Loss to open ocean	0.02	-0.01
National[z]	**Wetlands**	Rural development	0.01	-0.01
National[aa]	**Wetlands**	Urban development	0.01	-0.01

[a] Acres converted multiplied by 1.2 MgC/ha loss as reported by Hutyra et al. (2011).
[b] Coulston et al. (2015).
[c] Range includes estimates of carbon in forest removals as reported in Zhou et al. (2013) and Woodall et al. (2015). Estimates do not account for carbon in harvested wood products; the net annual change of CO_2 contained in harvested wood products (HWPs) and HWPs in solid waste disposal sites (SWDS) is estimated by U.S. Environmental Protection Agency (2015) to be 70.8 MMT CO_2.
[d] Estimate of cuttings only as reported by Coulston et al. (2015). Estimates do not account for carbon in harvested wood products.
[e] U.S. Environmental Protection Agency (2015).
[f] Coulston et al. (2015).
[g] Represents range of wildfire emissions data from 2009 to 2013, to represent variability (U.S. Environmental Protection Agency 2015).
[h] Coulston et al. (2015).
[i] U.S. Forest Service (2015b).
[j] Coulston et al. (2015).
[k] U.S. Forest Service (2015c).
[l] Coulston et al. (2015).
[m] Coulston et al. (2015); King et al. (2007).
[n] Eagle and Olander (2012).
[o] Eagle and Olander (2012).
[p] U.S. Environmental Protection Agency (2015).
[q] U.S. Environmental Protection Agency (2015).
[r] Eagle and Olander (2012).
[s] Eagle and Olander (2012).
[t] U.S. Environmental Protection Agency (2015).
[u] U.S. Environmental Protection Agency (2015).
[v] Eagle and Olander (2012).
[w] Eagle and Olander (2012).
[x] Present area as reported by Dahl (2011) multiplied by annual sequestration rate of 40.1 g/m^2 as reported by Zhu and Reed (2014).
[y] Present area as reported by Dahl (2011) (average of annual acreage impacted over 2004-2009) multiplied by annual

sequestration rate of 40.1 g/m^2 as reported by Zhu and Reed (2014).
[z] Present area as reported by Dahl (2011) (average of annual acreage impacted over 2004-2009) multiplied by annual sequestration rate of 40.1 g/m^2 as reported by Zhu and Reed (2014).
[aa] Present area as reported by Dahl (2011) (average of annual acreage impacted over 2004-2009) multiplied by annual sequestration rate of 40.1 g/m^2 as reported by Zhu and Reed (2014).

Table 3. Land Management and Land-Use Change Drivers Contributing to Increased Carbon Storage

Region	Land-Use Category + Ownership	Drivers	Land Area	Indicative Annual Flux (MMT CO_2e)
National[a]	**Settlements, private**	Urban forests	50.2	89.5
National[b]	**Forest, public, private**	Forest growth – range of accounting methods	No data available	347.2 to 1,273.1
Pacific Northwest[c]	**Forest, public, private**	Forest growth – net removals	84.0	124.7
Southeast[d]	**Forest, public, private**	Forest growth – gross	178.4	527.2
Southeast[e]	**Forest, private**	Cropland conversion to forest	0.7	85.8
National[f]	**Forest, private**	Conservation/ easements/set-aside	3	No data available
National	**Forest, public, private**	Afforestation	No data available	No data available
National[g]	**Forest, public, private**	Forest aging	No data available	Significant uncertainty
National[h]	**Forest, public, private**	Nitrogen application	Significant uncertainty	Significant uncertainty
National[i]	**Forest, public, private**	Increased CO_2 Levels	Significant uncertainty	Significant uncertainty
National[j]	**Cropland, private**	Conservation/ easements/set-aside	No data available	53.1
Midwest and Southeast[k]	**Cropland, private**	Conversion to no till	94.1 to 137.2	46 to 67.2
National[l]	**Cropland, private**	Diversify annual crop rotations	113.7	-78.2 to 78.2
National[m]	**Cropland, private**	Winter cover crops	15.7	-0.6 to 20.3
National	**Cropland, private**	Improved productivity	Significant uncertainty	Significant uncertainty
National[n]	**Grasslands, private**	Cropland conversion to grassland	34.1	8.8
National[o]	**Wetlands**	Conservation/ easements/set-aside	0.1	0.1
National[p]	**Wetlands**	Natural reversion		

[a] U.S. Environmental Protection Agency (2015).
[b] Range based on forest growth estimates in U.S. Environmental Protection Agency (2015) (low) and Woodall et al. (2015) (high).
[c] Hudiburg et al. (2011).
[d] Coulston et al. (2015).
[e] Calculated as the net of forest-to-agriculture and agriculture-to-forest transitions as estimated by Coulston et al. (2015).
[f] Pinchot Institute for Conservation (2011); Natural Resources Conservation Service (2015b).
[g] Coulston et al. (2015).
[h] King et al. (2007).
[i] King et al. (2007).
[j] Includes total 2013 mitigation of Conservation Reserve Program and Natural Resource Conservation Service (p. 71) (U.S. Department of State 2015).

[k] Range reflects average estimate of per acre sequestration as reported by Eagle and Olander (2012) (0.49 tCO_2e per acre) multiplied by 24 (low range estimate) to 35 (high range estimate) percent of cropland acres (392 million acres) (U.S. Environmental Protection Agency 2015) currently estimated to be under no-till management (Eagle and Olander 2012).
[l] Estimated based on increased diversification on 46 million ha of existing cropland, multiplied by observed per-ha average change in soil carbon as reported in Eagle and Olander (2012).
m Range includes estimates of per acre sequestration as reported by Eagle and Olander (2012), multiplied by 4 percent of total current cropland, 392 million acres, estimated to be the acreage currently managed under winter cover crops as discussed in Eagle and Olander (2012). NOT relevant for dry regions (Rocky Mountains, Great Plains, PNW). Eagle and Olander (2012).
[n] U.S. Environmental Protection Agency (2015).
[o] Present area as reported by Dahl (2011) (average of annual acreage impacted over 2004-2009) multiplied by annual sequestration rate of 40.1 g/m^2 as reported by Zhu and Reed (2014).
[p] Present area as reported by Dahl (2011) (average of annual acreage impacted over 2004-2009) multiplied by annual sequestration rate of 40.1 g/m^2 as reported by Zhu and Reed (2014).

2.3. Sources of Information Gaps

The information gaps in Table 2 and Table 3 owe to (1) gaps in data collection, (2) gaps in data organization and reporting, (3) scientific uncertainty about the net effect of natural phenomena, and (4) lack of consensus in the literature about how to account for drivers with potential indirect effects like removals. There is little information on how these drivers change over time—information that would help to prioritize various drivers on the basis of their likely relative importance in the future. These information gaps are elaborated below.

2.3.1. Scale of Mitigation Potential of Drivers

The limitation of this analysis is that it does not provide a sense of scale for mitigation potential of drivers that currently play a small role in the carbon sink. This may provide a skewed picture of priority areas for focus. For example, forests become a clear priority as a result of this analysis, while soil carbon enhancement on croplands and grasslands might be downplayed. It is important to consider these results in tandem with Section 4's review of mitigation potential assessments. Further work under the LCPR initiative would look to account for future mitigation potential when setting policy priorities, including promotion of soil carbon on cropland and grassland. Expert input indicates soon-to-be-published analysis will underline the critical role soil carbon management can play in enhancing the U.S. carbon sink.

2.3.2. Conversion to Settlements and Cropland

The U.S. GHG Inventory does not explicitly describe the carbon implications of conversion of grassland, cropland, forest, or wetland to settlement. Regional estimates are available in the literature (Hutyra et al. 2011; Coulston et al. 2015). Experts indicate that lack of spatially explicit settlement conversion data is the reason for excluding this information from the inventory.

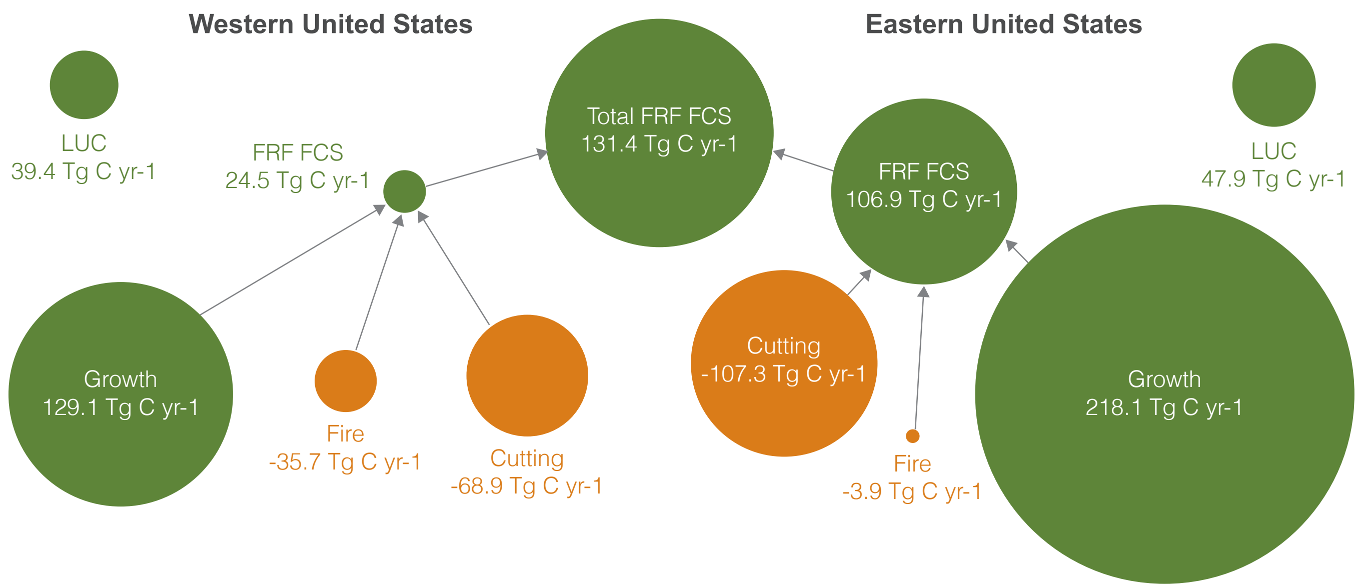
Recent studies suggest urban soils may play a larger-than-thought role in the overall carbon budget of human settlements. Churkina et al. (2010) found that 64 percent of carbon storage in urban settlements was attributed to soil. Further research is needed to quantify carbon storage in settlements as well as the carbon flux from land conversion to settlement (Raciti et al. 2011; Raciti et al. 2012; Lilly et al. 2015). Given projections of increased settlement growth, understanding of the multiple factors contributing to settlement carbon storage across regions and studies is necessary for accurate emissions reporting (Hutyra et al. 2011).

2.3.3. Growth, Removals from Forests and End Uses

All drivers of changes in forest carbon need to be considered in an integrated way. The net change in carbon in forests remaining forests is approximately equal to biomass growth minus removals (harvesting and thinning) and any natural losses such as fire or insects/disease. Figure 3 shows how USFS disaggregates these drivers in the updated U.S. Forest Carbon Accounting Framework (Woodall et al. 2015 – the word "cutting" is used rather than "removals").

To understand the net climate implications of forest management practices, this system needs to be looked at comprehensively. For example, in southern and northern U.S. forests relatively high harvest and regrowth rates result in a significant net carbon sink (Coulston and Wear 2015). The end uses of removals also need to be tracked. Depending on their end use, harvested wood products (HWP) can store carbon from 0 to 5 years or to more than 100 years (Pingoud et al. 2006). The USFS is currently working to update forest carbon accounting frameworks in order to account for carbon stored in HWPs, but the timing for this update is uncertain. Furthermore, placing limits on removals in a finite region may result in market leakage—that is, an increase in wood products demand in regions with no harvest and thinning limits (Murray et al. 2004). Additional analysis that accounts for market end uses and carbon leakage is needed. Such analysis would support development of forest management principles for optimizing carbon storage and fossil fuel offsetting alongside other management priorities.

Figure 3. U.S. Forest Carbon Accounting Framework Depiction of National Forest Carbon Drivers in 2011



FRF = forest remaining forest, FCS = forest carbon sequestration, LUC = land-use transfer carbon

Source: *Woodall et al. (2015).*

2.3.4. Wood Products Markets, Biomass Markets, Bioenergy

Wood product, biomass, and bioenergy markets are not considered primary drivers of land carbon change, but some experts believe that if they were strengthened they would support the land-use value of forests and reduce conversion of forests to other land uses (Forest-Climate Working Group 2014). The literature provides some indication of the emissions benefits of utilizing wood products or bioenergy in place of fossil fuel- or nonrenewable-based alternatives (Lippke et al. 2011; White et al. 2013), but additional data on the landscape-scale impacts of biomass and wood demand on land management and land-use change would illuminate the net emissions impact of supporting wood product and bioenergy markets. Note that there is ongoing discussion of the net carbon effects of bioenergy use in support of finalization of EPA's Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources. This report does not seek to enter into that discussion, but does acknowledge the important role this Framework could play in standardizing emissions accounting for bioenergy.

2.3.5. Forest Aging

The rate at which forests sequester carbon varies by age and is still questioned in the literature. Coulston et al. (2015) predict that aging of forests in the Southeast could result in a 9.5 percent decrease in carbon accumulation between 2014 and 2018. Other recent studies suggest that large, older trees continue to sequester carbon at increasing rates, undermining the hypothesis of old-growth-forest carbon sequestration plateau or decline (Stephenson et al. 2014). Whether higher sequestration rates in individual trees equate to greater carbon storage in tree stands remains to be determined, given higher mortality rates in larger trees and decreased stand density in old-growth forests (Stephenson et al. 2014). Additional analysis of where forest age creates risk of carbon sequestration plateau or decline should be considered. This risk may ultimately be an important consideration for localized tailoring of forest management strategies.

2.3.6. Cropland Management and Improved Productivity

Without significant commodity crop yield improvements over the last century, researchers estimate cropland would occupy three to seven times its current extent (Wang et al. 2015). It is unclear whether continued improvements contribute to avoided loss of land carbon emissions and whether they are a useful tool to enhance land carbon. The USDA Economic Research Service (ERS) estimates that if research and development spending were raised each year by 1 percent in real terms, the annual rate of agricultural total factor productivity (TFP) growth would grow 1.46 percent between 2010 and 2050, compared with 1.42 percent between 1948 and 2011 (Wang et al. 2015). This increase would enable the U.S. farm sector to keep pace with increasing domestic and global food demand with its current level of resource use. On the other hand, if public research funding remains constant in nominal terms at approximately $1.6 billion for the next few decades, TFP growth would likely slow (Wang et al. 2015). In addition to productivity, other interventions on cropland, such as agroforestry, have the potential to improve carbon outcomes. A number of mitigation options could ultimately become major drivers of the carbon sink, but this analysis is focused on existing drivers.

2.3.7. Climate-Related Drivers

Drought, extreme weather, increases in atmospheric CO_2, and reduced habitat suitability are all drivers related to climate change that could both increase and decrease land carbon storage potential. The literature reflects significant uncertainty about these drivers (King et al. 2007; Le Quéré et al. 2009; Xiao et al. 2011). Quantifying them could illuminate the limits to policy's capacity to enhance the carbon sink.

2.3.8. Insect and Disease, Wildfire

Although fire, insect, and disease contribute to forest carbon loss on a landscape scale, Coulston et al. (2015) indicate that Southeast areas affected by these drivers continue to exhibit carbon growth year over year. A greater understanding of the impact of fire, insects, and disease on the land carbon sink requires comparison to carbon growth in a business-as-usual scenario (without fire/insects/disease), but this analysis is not available.

Furthermore, maintaining carbon storage capacity in forests requires building resiliency to drought, insects, and wildfire. It is difficult to determine on relatively small scales how this resiliency translates into management practices that optimize ecological integrity and carbon storage. In the western United States, drought and decades of fire suppression have increased the occurrence and severity of wildfires, a major source of carbon emissions, but the net carbon balance of forest management practices associated with wildfire risk reduction are a subject of debate (McKinley et al. 2011; North and Hurteau 2011; Campbell et al. 2012). A better appreciation of these complexities is necessary to optimize land carbon in public and private forests, especially in the West, where wildfire management is a high priority. It appears that optimization of carbon and ecosystem integrity would warrant highly localized forest management plans, tailored to local fire, disease, and insect risk profiles. Furthermore, wildfire on non-forested land is currently not accounted for in the U.S. GHG Inventory. However, the U.S. Forest Service is working to include above-ground biomass in woodlands and shrublands in the 2016 inventory. Loss of carbon due to wildfire on these landscapes would need to be included in the inventory accordingly.

2.3.9. Demographics

Private forest owners are aging; one-third are 65 years of age or older (U.S. Forest Service 2008). Likewise, the average age of farm operators is 58 years. As landowners continue to retire or pass away, the resulting land transfers could have significant implications for land management and land use (U.S. Department of Agriculture 2014a).

2.3.10. Wetlands

Most quantitative measurements of wetland carbon and emissions fluxes have focused on the topmost meter of peat lands and rice paddy soils. A complete national inventory of soil carbon in wetlands is required to fully quantify this land-use category (McGuire et al. 2011). The U.S. GHG Inventory currently reflects carbon emissions only from peatlands that remain peatlands. The EPA is working to include coastal wetlands in the inventory by fall 2016 (Sutton-Grier and Moore 2015).

Quantifying the greenhouse gas balance in wetlands is inherently difficult because the potential of wetlands to be a sink or source varies over space and time. Small changes to a wetland can significantly alter the balance of greenhouse gases. Wetlands are unique in that they are generally sinks for carbon dioxide and sources of methane. Whether methane is partially or totally offset by carbon sequestration ultimately determines whether a wetland is classified as a sink or source. This relationship can be easily altered by natural and human disturbances, which means wetland management and land-use conversions play critical roles in determining present and future wetland GHG balances. These variations make the net impact of wetlands on climate difficult to assess at scale (Petrescu et al. 2015).

2.3.11. Alaska

In 2008, carbon storage estimates for south central and southeastern coastal Alaska were included in the U.S. GHG Inventory for the first time. Efforts to better understand forest carbon stock are under way and will be reflected in future inventories as emerging research techniques are vetted and adequate funding resources are available (U.S. Environmental Protection Agency 2015). Preliminary research finds that managed forest carbon stock in interior Alaska could equal 15,000 MT of carbon, or roughly 37 percent of the entire managed U.S. forest carbon stock in the U.S. GHG Inventory (U.S. Environmental Protection Agency 2015). Lack of robust data and consequent failure to include Alaska in broader conversations about U.S. land carbon could have significant impacts on the success of proposed policy interventions.

The most broadly distributed terrestrial biome globally and in Alaska is the boreal biome, a dense forest area with high carbon content. Soils of this biome, spanning upper latitudes of North America and Eurasia, contain 49 percent of the global terrestrial forest carbon (Douglas et al. 2014). Ongoing research efforts have identified roughly 46–49 million hectares of managed forestland in Alaska's interior (U.S. Environmental Protection Agency 2015). It is likely that much of this land area is classified as boreal forest. In Alaska, this ecosystem has become increasingly vulnerable to carbon loss as a result of climate change, which will lead to major landscape changes over the next 20 to 50 years. Changing weather patterns and more intense fire disturbances are driving landscape change—affecting forest composition and permafrost stability. These ecological shifts have long-term impacts on carbon cycling (Douglas et al. 2014).

Furthermore, Alaska has 130 million acres of wetlands, representing 63 percent of the nation's wetland ecosystems (Alaska Department of Environmental Conservation 2015b). As of 2009, only 40 percent of Alaska had wetland mapping and no funding for new mapping activities (Tiner 2009), while the last state-level Wetlands Status and Trends report produced for Alaska was in 1994. The state-level Alaska Greenhouse Gas Inventory (1990–2010) found that net emissions from LULUCF and wildfires were -20 MMT CO_2e in 2010 (Alaska Department of Environmental Conservation 2015a). Judging by the extent of forest and wetland cover in the state, estimated emissions appear low. Aggregated emissions totals do not allow these emissions to be attributed to any particular land-use category or land-use change.

2.4. Conclusions Regarding Land Carbon Drivers

Although U.S. agencies continue to improve the understanding and presentation of factors influencing the U.S. carbon sink, significant work remains to estimate the net atmospheric effects of key drivers like forest management, to estimate the influence of drivers over time and into the future, and to determine the potential impact of natural drivers like forest aging, drought, and fire. Targeted analysis and presentation of these issues can support policy development and prioritization.

The largest drivers of the U.S. carbon sink revolve around forestry; forest growth and forest removals are the largest determinants of sink size. Calculating the net effects of modified forest management practices is far from straightforward, particularly when accounting for natural forest dynamics, market effects, avoided wildfire or insect impacts, and offsetting of fossil fuel emissions. Therefore, a key recommendation is to develop principles that can account for these factors and that can be reflected in new policy.

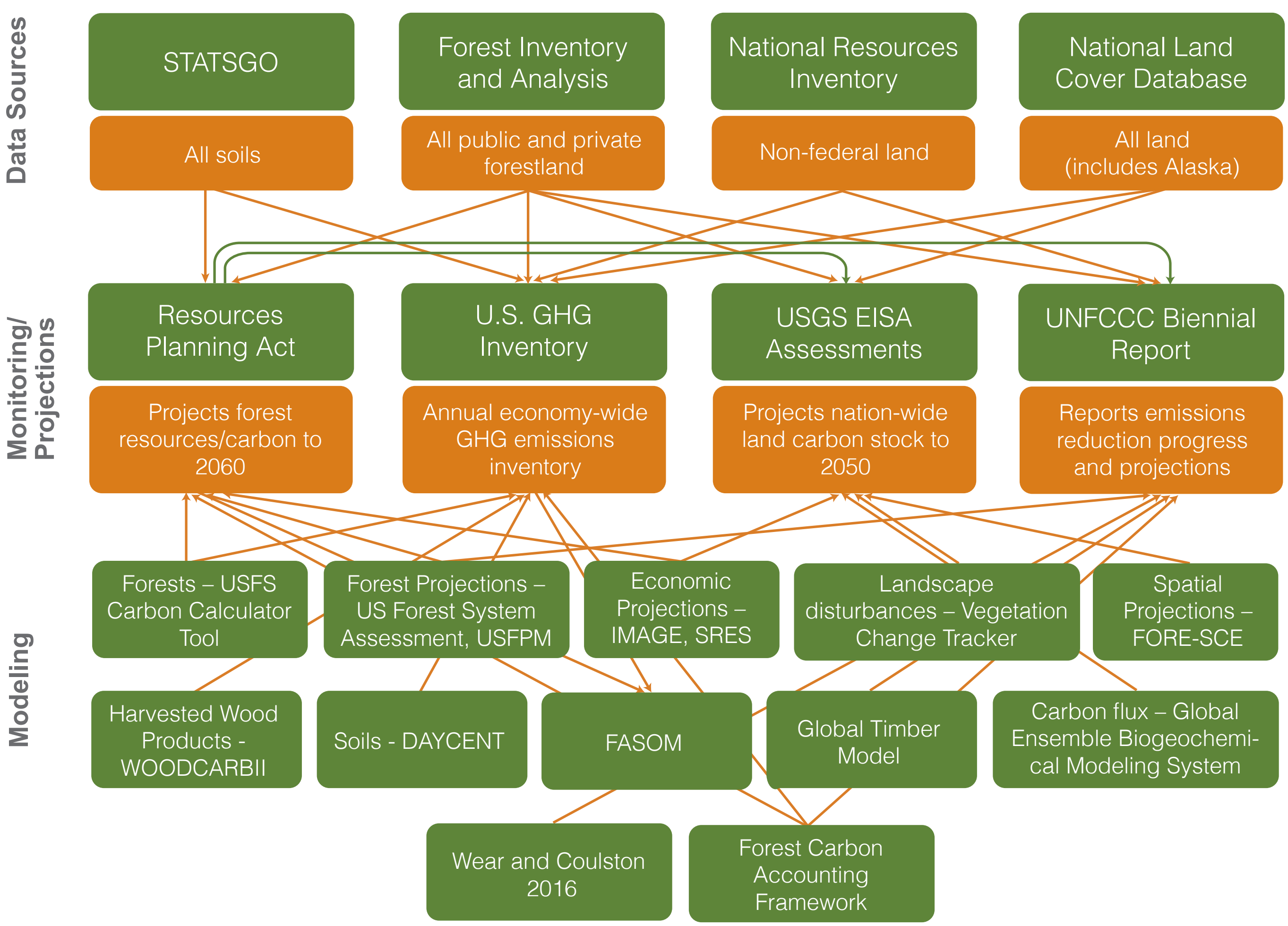
3. Projections of U.S. Land Carbon Stock

Presented below are take-aways from U.S. government programs and independent research that indicate where the U.S. carbon sink is likely headed in the coming decades. This information is critical for understanding the need for and potential impacts of any new policies.

A variety of related and overlapping efforts support understanding of past, current, and future land carbon stock levels in the United States (Figure 4). These efforts lead to a variety of results and sometimes conflicting indications of land carbon trends. As discussed below, a number of estimates of expected U.S. land carbon stocks and emissions have been released in recent years. A great many more are expected to be released soon. In addition to indicating U.S. forest and agricultural carbon sequestration trends, they yield insight into the processes by which information is fed into research and policy and how past data gaps have been identified and addressed.

Figure 4 provides an overview of the relationships among major GHG inventory, modeling, projection and reporting initiatives in the United States. It includes programs that track past and current levels of U.S. land carbon (U.S. GHG Inventory) and that provide projections of future U.S. land carbon (Resources Planning Act, USGS EISA assessments, UNFCCC Biennial Report). Figure 4 is not meant to conflate the objectives of these programs, but rather to showcase how each of the programs relies on a diverse network of data sources and modeling approaches to generate information that would inform U.S. policy for managing land carbon. These programs largely underlay the U.S. government's understanding of the state of the land carbon sink and its trajectory in coming decades.

Figure 4. Science, Data, and Monitoring Programs for Land Carbon in the United States



A selection of government reports and independent research that provide U.S. land carbon projections, along with sources of variation in reported estimates, is reviewed below. Given the pace at which reports are revised and released, this discussion is not intended to provide the basis for critical lessons or future policy directions. Rather, it is intended to indicate the evolution of carbon projections and ways, according to the current best-available science, to enhance the land carbon sink.

3.1. Projected Trends: Existing Estimates and Reporting Processes

The range of future LULUCF estimates in the BR2 are based on a series of modeling projections by EPA and USDA/USFS. In the USDA/USFS-led analysis, projections are driven by population growth, expansion of settlements, and conversion of forests. To the extent that projected relationships between high population growth and conversion hold and in the absence of aggressive policy action, the carbon sink may trend towards low-end estimates. For the EPA-led analysis, outcomes are influenced by the extent to which landowners are driven by strengthening forest products markets and carbon pricing signals. Should these conditions hold, investment in forests may allow for a sustained carbon sink at the higher end of projections. The BR2 indicates optimism for achieving higher sequestration levels given historical sink values and early action taken under the Climate Action Plan, including USDA's 10 Building Blocks, to bolster land carbon.

Other U.S. analysis on the carbon sink include USFS reports on the status and trends of forest and rangeland resources in the U.S. every five years as part of its obligations under the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974. The most recent assessment was completed in 2010 (U.S. Forest Service 2012a). Rather than examine changes in relation to a single assumed baseline, the 2010 RPA assessment employs a series of projections that are linked to IPCC assumptions and projections of global population growth, economic growth, bioenergy use, and climate. Across scenarios, the 2010 RPA assessment finds that carbon stored in forests will peak between 2020 and 2030 and thereafter decline; at some point, according to the assessment, forests could become a net carbon source. Other USFS studies also support the notion of a declining U.S. forest carbon stock (Wear and Greis 2013; Wear and Coulston 2015). Wear and Coulston (2015) find that a gradual aging of existing forest stocks will contribute to a decline in forest carbon sequestration. In some areas of the country (Rocky Mountains), this decline, combined with possible forest disturbances, could lead to forests becoming a net carbon source. In other areas (South and North), higher rates of harvest activity and subsequent forest regrowth contribute to a lesser decline in forest carbon storage across multiple scenarios.

In fulfillment of the Energy Independence and Security Act of 2007's requirement to assess carbon stock and flow in U.S. ecosystems, the U.S. Geologic Survey has developed multiple integrated assessments of ecosystem carbon sequestration and GHG flux in recent years (Zhu et al. 2011; Zhu and Reed 2012; Zhu and Reed 2014). Like other recent USFS efforts, the USGS ecoregional assessments evaluate sequestration under multiple scenarios, informed by data on historical land-cover change from the USGS Trends project. Although these assessments find carbon stock and flux results to be highly variable among multiple model runs, ecoregions, and ecosystems, they indicate a general trend of increasing carbon storage but at a decreasing rate. Other recent USGS projections suggest a declining contribution of federal lands to U.S. national carbon storage relative to private lands (Tan et al. 2015) and a decline in expected sequestration on forestlands (Zhao et al. 2013; Tan et al. 2015).

3.2. Projected Trends: Agreement and Uncertainty

The projections reviewed above suggest a range of possible futures, including the possibility of a slowing or even declining sink. Across projections there is significant sensitivity to political, economic, social, and ecological assumptions. Specifically, all projections are forced to confront considerable uncertainty about future conditions. Variations in projection estimates are therefore unsurprising, but nonetheless complicate efforts to anticipate and plan an appropriate policy response. For this reason, enhancing data, monitoring, and projection capacities is an important component of any intervention to enhance U.S. land carbon.

4. Assessments of GHG Mitigation Potential

A review of existing GHG mitigation potential assessments suggests an opportunity to improve on business-as-usual scenarios—that is, to enhance the land carbon sink and support reductions in economy-wide GHG emissions. Because the findings of the existing literature are heavily dependent on the interventions investigated and the modeling assumptions used, general statements about the scale of mitigation potential achieved through interacting policies, programs, and practices are difficult to make.

Fortunately, long-term interest in forest and agriculture as a tool to mitigate GHG emissions has led to a large number of economic analyses and reviews in both the peer-reviewed and gray literature. Multiple estimates of mitigation potential under specific policy and market scenarios have been conducted since the mid-1990s (e.g., Barker et al. 1995; Murray et al. 2005; English et al. 2010; Nepal et al. 2013). More generalized assessments and reviews of the abatement costs of individual mitigation strategies also exist (Newell and Stavins 2000; Richards and Stokes 2004; Lubowski et al. 2006). Summaries and reviews such as Eagle and Olander (2012), McKinley et al. (2011), and ICF International (2013) provide overviews of practice-based mitigation potential, along with discussions of uncertainties, trade-offs, and co-benefits.

In addition to specific estimates of mitigation potential, the literature provides insight into the factors that can influence both the cost and availability of GHG mitigation in forest and agricultural sectors. For example, biophysical factors, such as growth rate and soil carbon sequestration rate, have been found to play important roles in determining the cost and amount of GHG abatement (Newell and Stavins 2000; Antle et al. 2002). Policy design can influence rates of activity uptake and program participation (Markowski-Lindsay et al. 2011; Dickinson et al. 2012; Miller et al. 2012) as well as the spatial response of land use and management practices (e.g., De La Torre Ugarte et al. 2009; Nalley et al. 2012). The inherent spatial variation in biophysical factors is exacerbated by spatial variation in individual practice or program participation decision making, further complicating estimation of aggregate GHG mitigation potential (Jianga and Koo 2013).

The following review of the literature includes a seminal report by the U.S. EPA, which provided a comprehensive overview of U.S. GHG mitigation potential in forestry and agriculture, and other works in the peer-reviewed and gray literature, including analyses of different policy and market drivers. It concludes with a brief summary of lessons and ideas for how a policy roadmap may leverage existing knowledge to plot out short-term mitigation options and long-term research needs.

4.1. Forests and Agriculture GHG Mitigation Potential: Learning from the Literature

Analyses of the GHG mitigation potential of forests and agriculture can be loosely categorized into studies that assess the imposition of carbon pricing in one or more sectors, the implementation of specific policies or programs to emphasize GHG mitigation, or the emergence of new markets with the potential to affect carbon storage and/or GHG emissions. Although this report attempts to draw high-level conclusions from this diverse body of work, that task is complicated by fundamental differences among the studies. As Schneider and McCarl (2006) caution in their own comparison of agricultural mitigation potential, "when comparing economic potential estimates from different studies, one should carefully examine the underlying assumptions particularly in terms of market price response, producer adjustment opportunities, regionality, and scope of allowed mitigation alternatives" (p285). Thus the array of studies reviewed here provides only a rough indication of the direction and magnitude of GHG mitigation yielded by comprehensive landscape policies and programs.

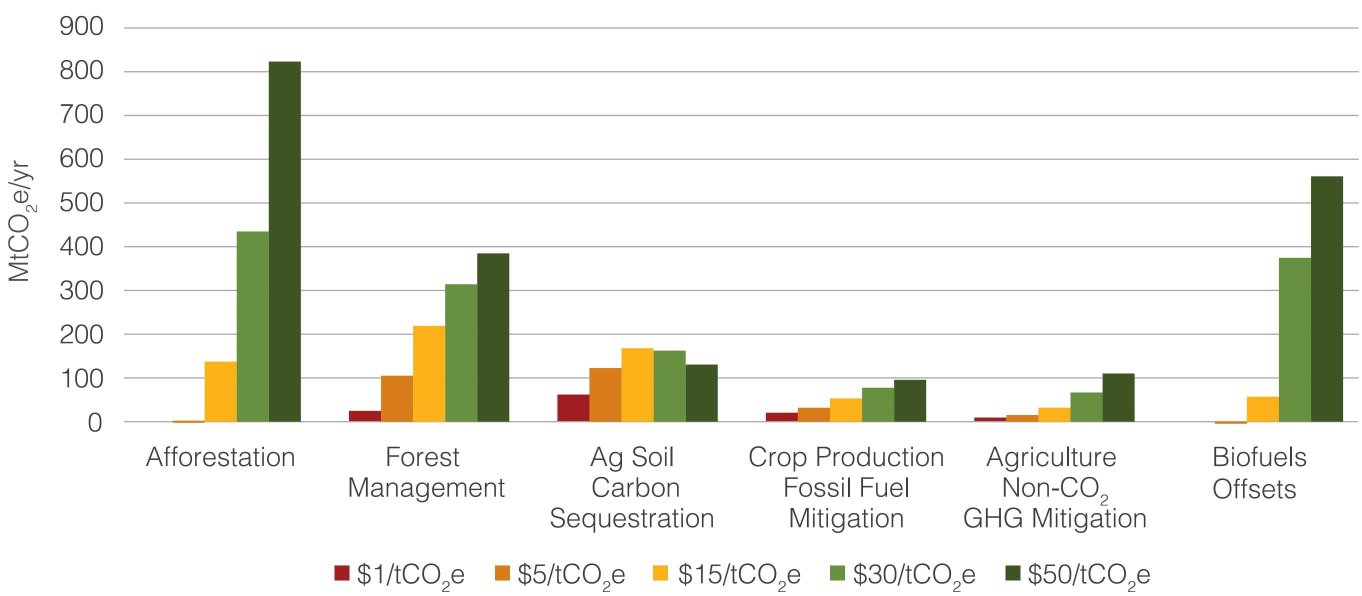
4.1.1. Carbon-Pricing Analyses

A price for carbon creates incentives to manage forest and agriculture lands so as to increase carbon storage and other GHG mitigation services. An important example of a carbon-pricing analysis is a 2005 report released by the EPA (Murray et al. 2005). The report set out to estimate the potential of different GHG mitigation strategies over time and using different carbon prices. It also sought to assess how the patterns of mitigation, including the contribution of individual GHG mitigation strategies and the distribution of mitigation from region to region, varied over time and under different pricing and policy implementation assumptions.

The 2005 EPA report assesses forest and agricultural sector response to the imposition of carbon prices using the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG). FASOM-GHG is a dynamic optimization model, meaning that management decisions in the model are chosen so as to maximize the long-run net present value of consumer and producer surplus. Importantly, carbon prices affect management decisions through both payments for additional GHG mitigation and penalties for additional emissions. This treatment of forest and agricultural activities differs from that in the programs envisioned in past climate legislation and in many contemporary voluntary and compliance offset programs, but it allows for a better understanding of the most efficient means to reduce atmospheric GHGs at a given price.

Several patterns emerge from the aggregate mitigation potential across six forest and agricultural mitigation strategies (Figure 5). The first is the outsized contribution of forest sector and biofuels components, especially at higher carbon prices. The second pattern is rising mitigation with rising carbon prices, except in the case of agricultural soil sequestration. When disaggregated across regions and carbon prices, forest sector activities in the southeast and south central United States are particularly competitive at all carbon prices. At lower carbon prices, agricultural soil sequestration activities in the Corn Belt, Lake States, and Great Plains are likewise competitive, whereas biofuels offsets in the northeast and other regions begin to come online at higher prices. The timing of GHG mitigation in part depends on the assumed price and price trajectory. At \$15/t CO_2e, for example, mitigation peaks in approximately 2080, falling slightly thereafter. Assuming \$30/t CO_2e, net GHG mitigation is much greater and continues to increase until plateauing in approximately 2090. The individual contributions of specific mitigation strategies likewise varies over time in each of these pricing scenarios; biofuels offsets play a much smaller role in the lower carbon price runs.

Figure 5. Annualized Net GHG Mitigation (2010–2110) by Mitigation Strategy and Carbon Price



Source: *Murray et al. (2005).*

The 2005 EPA report is notable in its comprehensive evaluation of GHG mitigation potential in the forest and agricultural sectors. Other carbon-pricing assessments employ a variety of analytical techniques and assumptions, leading to a wide range of mitigation cost and potential estimates. Although this variety complicates direct comparisons of studies and prevents universal conclusions from being drawn, the assessments nonetheless contribute to basic understanding of system response under different policy and market conditions.

One approach to estimate the cost of GHG mitigation is to compile the individual cost components necessary to achieve a unit of GHG mitigation (Richards and Stokes 2004). This so-called engineering approach can be fairly simple and analytically straightforward, providing insight into the cost of implementing individual activities or ranking the cost-effectiveness of a suite of activities (e.g., Galik et al. 2012). Scaling the results of such analyses is complicated, however, because capability to capture all opportunity costs and all indirect effects that may result from project implementation is limited. To address this problem, other analyses have adopted more complex methodologies for developing assessments of both costs and magnitude of potential (e.g., Elberg Nielsen et al. 2014).

A second approach is to observe historical changes in management behavior and to estimate, econometrically, the relationship between adoption of activities to increase GHG mitigation and changes in carbon price. An advantage of studies that take this approach is the potential to capture otherwise-unobserved drivers of practice adoption that could affect the cost of generating a given unit of GHG mitigation. For this reason, costs estimated econometrically are often higher than those generated by other approaches (Elberg Nielsen et al. 2014). Nevertheless, estimates from econometric analyses indicate that carbon sequestration costs are similar in magnitude to energy sector mitigation costs, implying that carbon sequestration could still contribute cost effectively to economy-wide GHG reduction objectives (Lubowski et al. 2006).

A third approach is to use an economic model to assess the optimal suite of management activities employed at a given carbon price under a given set of conditions. The 2005 EPA report described above uses this approach, as do numerous other analyses. These additional studies provide a broader understanding of mitigation potential under an expanded array of policy, pricing, and market assumptions. They suggest, for example, relatively small contributions from agricultural practices, relatively large contributions from forest management activities, and variations in both prominent mitigation activities and aggregate contributions from different regions of the country (Baker et al. 2010; Adams et al. 2011; Haim et al. 2014).

A recent emphasis in carbon-pricing studies that make use of economic models is the importance of different assumptions about participation in GHG mitigation activities. For example, studies suggest that voluntary participation in a carbon-pricing scheme may not be as effective in slowing conversion of forestland as mandated participation and may come with a higher marginal cost of GHG reduction, even failing to achieve any participation at low payment levels (Im et al. 2007; Latta et al. 2011). Voluntary participation may also result in significant leakage effects and differences in the estimated welfare of enrolled landowners and that of non-enrolled landowners (Nepal et al. 2013).

Other studies emphasize the importance of assessing the interconnections among different regions or markets. These analyses find, for example, the potential for inter-regional shifts in activities owing to non-uniform implementation of GHG mitigation activities, underscoring the importance of accounting for leakage (Hertel et al. 2008; Golub et al. 2009). Others find that leakage varies depending on the region targeted for GHG mitigation, with areas possessing significant GHG mitigation capacity potentially offsetting losses elsewhere (Haim et al. 2015). In addition, analyses suggest that benefits accrue differently to producers in regulated regions and in non-regulated regions (Lee et al. 2007).

Finally, effort has been devoted to capturing a large suite of policy options and policy portfolios. Analyses considering policy portfolios suggest that mitigation effects can be compounding and that multiple interacting policies can generate a wide range of potential mitigation outcomes (Alig et al. 2010). Wide variation in the spatial distribution of costs and benefits both within and across policy scenarios can also result (De La Torre Ugarte et al. 2009; English et al. 2010). For example, one analysis of the influence of different mitigation mechanisms, fixed prices, price change limits, and acreage limits found that the amount of GHG mitigation available at a given price varies by as much as -55 percent to +85 percent as compared to a base model configuration (Schneider and McCarl 2006).

4.1.2. Analyses of Practice- or Program-Based Approaches

Carbon pricing is an efficient mechanism to increase carbon storage and GHG mitigation in forests and agriculture. In the absence of a carbon price, however, GHG mitigation could be encouraged through a variety of other financial incentives, regulatory reforms, or program design considerations. One category of interventions includes a change in policy or practice implementation, such as a change in the emphasis or terms of a farm conservation program or in the patterns of federal forest management. Research suggests, for example, that decreasing rates of Conservation Reserve Program (CRP) reversion to production cropping can generate substantial carbon gains, estimated in the past to be potentially as high as 15 MtC/yr assuming no reversion and 30 MtC/yr assuming no reversion and additional afforestation (Barker et al. 1995). Changing the manner in which farm support programs are implemented can also achieve significant GHG mitigation. One study estimated that scaling back existing support programs while increasing payments for carbon could achieve additional carbon sequestration of up to 104 MtC/yr at a federal cost savings of approximately $6.2B/yr (Callaway and McCarl 1996). On private lands, establishment of forest retention requirements have been shown to slow the loss of forest cover (Ferris and Newburn 2014). On public timberlands, it may be possible to increase net carbon storage either through an absolute reduction in public land harvest activity (Depro et al. 2008) or by coupling public-land harvest reductions with private-land harvest increases so as to take advantage of the higher-productivity stands on private lands (Im et al. 2010).

Many studies assess the potential GHG mitigation achieved through implementation of specific individual practices. Directly relevant to this report are meta-analyses conducted by Eagle and Olander (2012), ICF International (2013), and Guo and Gifford (2002). In their review of soil carbon change associated with land-use change, Guo and Gifford (2002) find that soil carbon generally declines as land transitions from pasture to plantation, from native forest to plantation, from native forest to cropland, and from pasture to cropland, but that it increases as land-use transitions from native forests to pasture, from cropland to pasture, from cropland to plantation, and from crop to secondary forest. In their examination of discrete mitigation practices, Eagle and Olander (2012) provide a comprehensive review of mitigation options as well as an assessment of data quality and research needs. Among those practices with a significant or moderate empirical research basis, the authors find that conversion to no-till or conservation tillage practices as well as establishment of cover crops and short rotation woody crops display the largest aggregate potential. Biochar application to croplands emerges as among the greatest high-potential but high-uncertainty mitigation options. ICF International (2013) also finds that a change in tillage practices is among the lowest-cost mitigation options available in crop production systems, but with the potential to reduce yield in the process. Among land retirement options, retirement of marginal lands and organic soils and restoration of forested wetlands have the lowest-cost GHG mitigation potential.

Similar assessments have been conducted for forest sector mitigation potential. Birdsey et al. (2000) summarize work on individual management interventions and present an overview of the time periods under which specific practices would achieve their targeted GHG reductions. They find that improved forest management activities, reduced harvests, and afforestation offer the greatest GHG mitigation potential, but that biomass energy, urban forestry, increased recycling, and increased use of long-lived wood products could likewise contribute to GHG reduction goals. In a more recent review of forest sector opportunities, McKinley et al. (2011) identify avoided deforestation, afforestation, decreased harvests, increased growth, biomass energy, wood product substitution, and urban forests as potential mitigation strategies. The mitigation potential offered by each strategy varies, as do expected co-benefits and potentially negative co-effects.

Despite significant research, the aggregate mitigation potential of wood product substitution and fuels treatment to reduce catastrophic wildfire remains uncertain. The increased use of wood products as a GHG mitigation strategy has featured prominently in the literature, but the magnitude of potential contributions to nationwide GHG reductions remains unclear. Life cycle assessment (LCA) studies of forest product substitution suggest substantial GHG mitigation potential on a unit-by-unit basis; such substitution could reduce GHG emissions 20-50 percent as compared to a steel- or concrete-built structure (Upton et al. 2008; Lippke et al. 2011). Meta-analyses have also estimated average displacement factors ranging from -2.3 tonnes of carbon (tC) to more than 15 tC per unit of wood used to replace other materials (Sathre and O'Connor 2010). Studies such as these are useful for assessing the full suite of trade-offs among individual product use decisions, but they are less definitive about the GHG implications of market responses to large-scale policy changes.

Though continued fire suppression efforts may be critical in preventing U.S. forestlands from becoming a large source of emissions (Hurtt et al. 2002), there is uncertainty about the role that fuel treatments play in wildfire reduction and GHG mitigation. In particular, considerable uncertainty attends the landscape-level GHG benefits of fuels reduction (McKinley et al. 2011). Fuel treatments can generate increased feedstock for bioenergy operations or wood products manufacturing, but they may also result in short-term carbon declines as material is removed (Finkral and Evans 2008; Evans and Finkral 2009; North and Hurteau 2011). Long-run carbon storage may increase as the risk of catastrophic wildfire lessens (North and Hurteau 2011), but some research suggests that repeated interventions are necessary to maintain the benefits yielded by the initial fuels reduction activity (Agee and Skinner 2005; Collins et al. 2011) and that situation-specific factors can influence the response of treated areas to future fires (Rhodes and Baker 2008). Still others argue that the net carbon implications of fuels treatment may be negligible (Mitchell 2015) and that even with the bioenergy benefits stemming from removed material, an increase in maximum stand carbon storage is necessary to yield net GHG improvements through fuels treatment (Hudiburg et al. 2011; Campbell et al. 2012).

4.1.3. Analyses of New Markets

New markets for forest and agricultural products can encourage carbon sequestration and GHG mitigation in several ways. These markets can stimulate demand for a product, increasing incentives for intensive management and decreasing incentives for conversion to other, lower-carbon land-use types (e.g., the transition from forest to agriculture or urban uses). These markets can also help to displace other emissions, such as using biomass to displace fossil fuels or wood-based building materials to reduce use of concrete and steel. As reviewed below, the contribution of new markets to GHG mitigation depends greatly on the land-use and land management change response as well as on assumptions regarding the performance of related markets (e.g., housing).

Some studies focus on feedstock and the economic viability of different production streams, finding, that targeted incentives and technological development are required for bioenergy to be competitive with fossil fuels and to achieve sizable market penetration (McCarl et al. 2000). Others find that the GHG implications of additional demand are dependent in part on assumptions about residue recovery and productivity changes (Abt et al. 2012). Still others evaluate national or regional potential under different assumptions and policy scenarios, finding that market-induced land-use change strongly influences the GHG benefit of expanded biomass use, leading to large spatial and temporal variations in patterns of carbon storage (Daigneault et al. 2012; White et al. 2013; Galik et al. 2015).

Like the carbon price analyses reviewed above, analyses of new forest and agricultural markets underscore the importance of regional and market linkages. For example, Ince et al. (2011) evaluate global forest sector response to additional U.S. demands for renewable energy and fuel and under changing oil price scenarios, finding that fuel feedstock production, softwood growing stock, and hardwood growing stock are all higher in 2030 than in 2006. The study also notes the importance of assessing related markets, in this case analyzing the connection between recovery of the housing market and production of residues to be used for fuelwood. Using the Global Trade Analysis Project's FARM model, Suttles et al. (2014) assess U.S. and EU renewable energy policy, finding that emissions reductions from bioenergy are greater than those from liquid biofuels.

4.2. Summarizing the Available Literature

The above-noted studies provide multiple lessons for development of a policy roadmap to increase GHG mitigation in the forest and agricultural sectors. Methodologically, these studies indicate the diversity of models and approaches used to assess forest and agriculture GHG mitigation policy (Table 4). No one approach or collection of components can be identified as best-practice; the choice of tool must be appropriate to the policy being assessed or the question being asked. For example, policies with the potential to affect commodity markets should be assessed with tools that can track market changes and potential indirect effects. Practices characterized by a large degree of spatial heterogeneity should be assessed with tools that provide for geographic disaggregation.

With regard to GHG mitigation potential and the means to generate it, the literature provides multiple important lessons. First, estimates of mitigation potential vary across both individual studies and assessed practices. Some general conclusions are nonetheless possible. According to a variety of studies, forest management and afforestation tend to provide the largest magnitude of carbon benefits. Within the forest sector, the costs of avoiding the loss of forest stands may be less than the costs of afforestation on a per-unit-of-carbon-stored basis. The costs of permanent conservation may also be less than the costs of preservation with allowable periodic harvests (Newell and Stavins 2000). The timing of GHG mitigation varies across strategies, however, with forest management benefits potentially realized before those from afforestation (Latta et al. 2011). Agricultural carbon management and GHG reduction practices tend to contribute less mitigation relative to forest-based practices, but they are potentially available at lower costs (e.g., Murray et al. 2005).

Viewing mitigation options from the perspective of a portfolio of policies, rather than a series of stand-alone or one-off policies, is also important (Alig et al. 2010). For example, land-use change provisions (reduced urban development, limited CRP reversion, fixed forest-agriculture transitions) have been shown to contribute small to moderate GHG benefits at the scale considered in the literature. Alternatively, land-use controls implemented in conjunction with policy to encourage bioenergy market development can lead to substantial net GHG emissions because production systems are provided less capacity to respond to changes in market conditions (Daigneault et al. 2012; Latta et al. 2013).

Also apparent from the literature is the strong role of pricing in encouraging GHG mitigation behavior. Generally, higher carbon prices yield greater carbon responses (Murray et al. 2005; Alig et al. 2010; Haim et al. 2015). A possible exception is when a fixed budget facilitates management activities, in which case a lower carbon price may allow inclusion of additional areas or individuals in the program (Nepal et al. 2013). It is also possible to meld carbon reduction policies into other forest and agricultural support programs to achieve "no regrets" policy outcomes that achieve GHG mitigation while operating within established budgetary constraints (Callaway and McCarl 1996).

With respect to program implementation, inter- and intra-regional variations in conditions are important to understand, as is leakage among regionally targeted programs (Galik et al. 2015; Haim et al. 2015). International efforts also influence domestic adoption of GHG-reducing practices, suggesting the importance of taking a global perspective in mitigation assessments (Lee et al. 2007; Golub et al. 2009). At the opposite end of the spectrum, research has shown that rates of individual landowner or land manager participation in carbon programs or practices may be below those assumed in early modeling assessments, limiting the amount of GHG mitigation actually achieved (Markowski-Lindsay et al. 2011; Galik et al. 2013). Attention should therefore be paid to the implications of program design and delivery for eventual uptake by targeted participants.

The existing suite of literature illuminates both opportunities for GHG mitigation through agriculture and forestry and the influence of program design and implementation on the timing and extent of that mitigation. It is nonetheless difficult to generate an estimate of maximum or expected GHG mitigation achievable through the complex array of policy and practices currently available to decision makers. To do so would require better alignment of model input data and business-as-usual assumptions so that analyses can better speak to one another, as well as agreement on the content of the portfolios to be assessed, including key design elements like regional targeting or specificity and the magnitude of the budget, acreage, or GHG targets. Such analyses would be a critical first step in better appreciating the opportunities for increasing U.S. land carbon stock in the near term and for addressing a potentially decreasing sink.

Table 4. Attributes of Select Forest and Agricultural Sector Modeling Analyses

Study	Model[a]	Type[b]	Time period	Region	Sectors[c]	Policy framework(s)	Components[d]					
Baker et al. (2010)	FASOM	IO	2000–2080	U.S.	F, A	Carbon price	LUC	EP	MCS MCG		PP	SER
Hertel et al. (2008)	GTAP	CGE	20 years	U.S./ global	F, A	Carbon price	LUC	EP	MCS MCG			SER
Adams et al. (2011)	FASOM	IO	2010–2060	U.S.	F, A	Carbon price/ offset	LUC	EP	MCS MCG		PP	SER
Nepal et al. (2013)	USFPM	RD	2010–2060	U.S.	F	Carbon price/ set-aside	LUC	EP	MCG	VP	PP	SER
Haim et al. (2015)	FASOM	IO	2010–2050	U.S.	F, A	Carbon price, Fixed forest/ag transition	LUC	EP	MCS MCG		PP	SER
Alig et al. (2010)	FASOM	IO	2000–2080	U.S.	F, A	Carbon price, Reduced development, Fixed forest/ag transition	LUC	EP	MCS MCG			SER
Abt et al. (2012)	SRTS	RD	2008–2037	SE	F	Renewable fuel/energy	LUC	EP		VP	PP	SES
English et al. (2010)	POLYSYS	RD	2010–2025	U.S.	F, A	Renewable fuel/energy	LUC	EP	MCS	VP	PP	SER
Galik et al. (2015)	FASOM/ SRTS	IO/RD	2010–2050	U.S., SE	F, A	Renewable fuel/energy	LUC	EP	MCS MCG	VP	PP	SER
Ince et al. (2011)	USFPM	RD	2006–2030	US, global	F	Renewable fuel/energy		EP	MCG		PP	SES
White et al. (2013)	FASOM	IO	2005–2035	U.S.	F, A	Renewable fuel/energy	LUC	EP	MCS MCG	VP	PP	SER
Daigneault et al. (2012)	TSM	IO	2010–2060	U.S., global	F, A	Renewable fuel/energy, Fixed forest/ag transition	LUC	EP	MCS MCG	VP	PP	SER
Latta et al. (2013)	FASOM	IO	2010–2040	U.S.	F, A	Renewable fuel/energy, Fixed forest/ag transition, No commodity substitution	LUC	EP	MCS MCG	VP		SER
Depro et al. (2008)	ATLAS	D	2010–2100	U.S.	F	Changes in harvest practice						SER

[a] ASMGHG, Agricultural Sector Model; ATLAS, Aggregate Timberland Assessment System; FASOM, Forest and Agricultural Sector Optimization Model; GFPM, Global Forest Products Model; SRTS, Sub-Regional Timber Supply Model; TSM, Timber Supply Model; USFPM, United States Forest Products Module; GTAP, Global Trade Analysis Project.
[b] IO, Intertemporal Optimization; RD, Recursive Dynamic; CGE, Computable General Equilibrium; D, Deterministic.
[c] F, Forestry; A, Agriculture.
[d] LUC, land-use change; EP, endogenous pricing; MCS, market connectivity-sector; MCG, market connectivity-geographic; VP, voluntary participation; PP, policy portfolios; SER, spatially explicit-regional; SES, spatially explicit-subregional.

5. Status of U.S. Land Carbon Stock Policies

A variety of federal, regional, and state policies, programs, and regulatory authorities that directly or indirectly affect or that could affect land carbon stock are described here. On the basis of key drivers of land carbon change and factors that determine the scale of mitigation potential, this analysis identifies major gaps in existing policies and opportunities for new policies that would generate significant additional carbon sequestration, supporting priority policy recommendations.

Programs and policies are organized in six general areas: data, monitoring, and projections; conservation; markets; other incentives; tax code; and regulation. Data, monitoring, and projections programs collect raw data, develop land carbon estimates, and create strategies for communicating and managing issues related to land carbon. Some of these programs also develop future projections of land use and management and related impacts on carbon storage. Conservation policies and programs include easement programs, technical assistance and funding for improved land stewardship, and several federal land management programs and policies. For most of these programs and policies, the primary driver is not carbon mitigation but rather improvement of biodiversity and wildlife habitat, protection of watersheds, reduction of wildfire risk, and enhancement of other ecological and social goals. Markets include the California cap-and-trade program and the Regional Greenhouse Gas Initiative (RGGI), both of which have protocols for demonstrating increased forest carbon storage that allow landowners to earn carbon offset credits. Other incentives come in the form of government loans and grants and that encourage markets for sustainable forest and agricultural products. Tax code refers to potential incentives and disincentives that could affect the economics of forest and cropland properties and the attractiveness of increasing land carbon. Regulations specify required practices or procedures for activities that could affect land carbon stock, such as mitigation of wetland loss under the Clean Water Act and protection or mitigation of at-risk species habitat under the Endangered Species Act.

Figure 6 shows how U.S. policies and programs (inventoried in Appendix A) interact with drivers of land carbon change. Drivers in the upper right corner receive a greater amount of public dollars and policy-affected acreage than drivers in the lower left corner. Grassland-to-cropland conversion appears to be the most policy-influenced driver due to the scale of funding for crop insurance and agricultural support programs. Grassland conservation easements are supported by many programs; the Conservation Reserve Program (CRP) is by far the largest policy at play here. Removals are estimated to be driven mainly by the Federal Wildland Fire Policy and the Land Management Planning Rule as well as by bioenergy support programs like the Biomass Crop Assistance Program (BCAP) and biorefinery loan guarantee programs. Given the uncertainty around the net carbon impact of forest removals described in Section 2, this driver is presented as such (yellow).

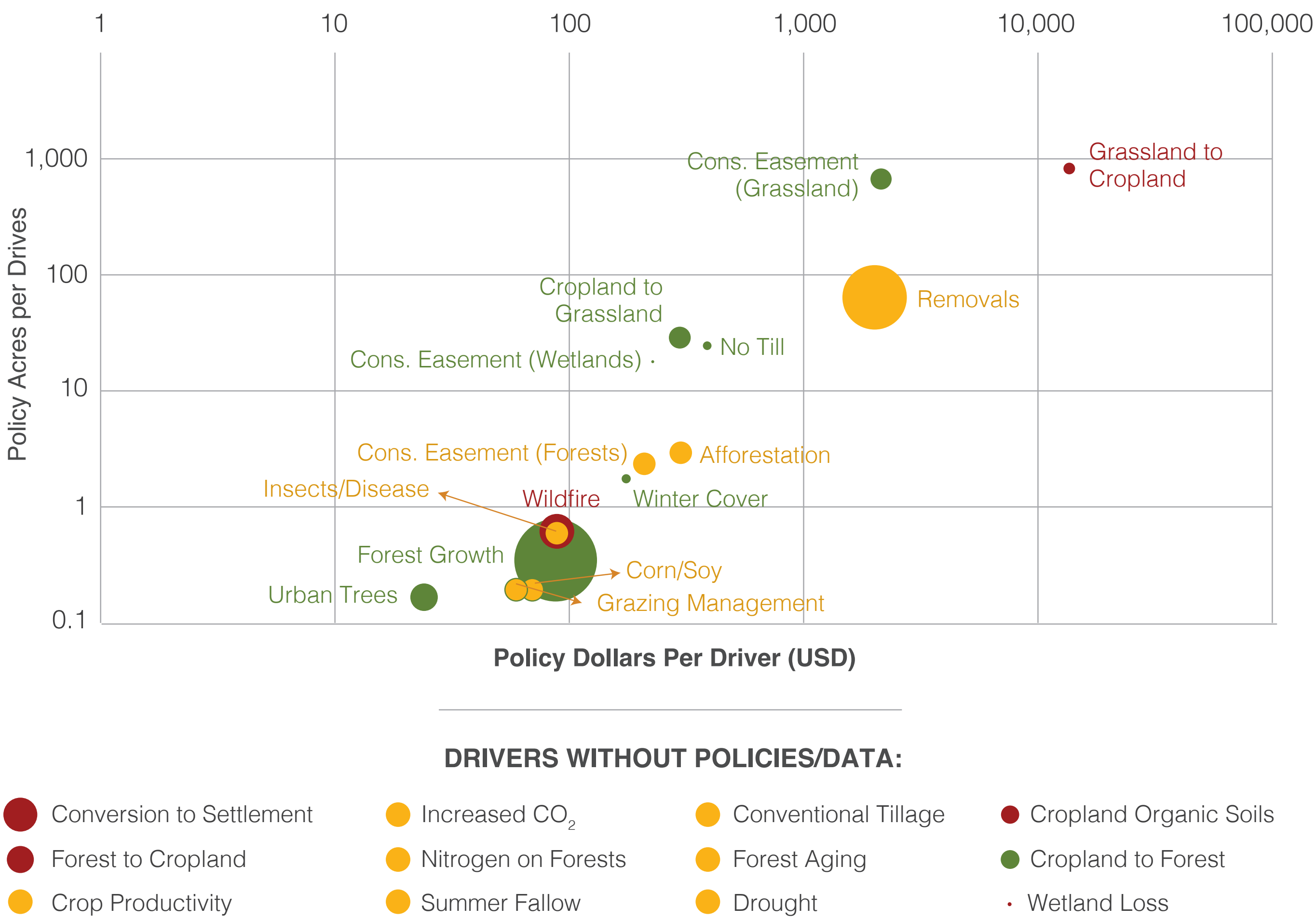
Existing policies and programs are less influential for land carbon drivers like forest growth, urban trees, and forest regeneration. In this analysis, the only policy currently driving forest growth is the California emissions trading program. One Forest Service program is dedicated to urban forests (the Urban and Community Forestry Program), and one program explicitly focuses on public forest regeneration (the Landscape Scale Restoration Program).

Policies were assigned to land drivers only when a direct and causal relationship could be assumed. For example, although the Environmental Quality Incentives Program (EQIP) incentivizes reduced or no-till practices, in turn reducing conventional tillage, only its impact on conservation practices is described. This strategy helps to avoid double-counting of policy impacts.

These findings are based on publicly available data and may not represent the total complexity of all government program impacts on various land carbon drivers. They are meant to provide an initial snapshot of existing policy priorities. In addition, this analysis does not consider the relationship between policies, market-based drivers, and land carbon (e.g., how commodity prices are effect and are affected by land use).

The information presented in Figure 6, combined with information about land carbon drivers and existing programs and authorities synthesized elsewhere in this analysis, allows for a simplified gaps analysis. Based on a thorough review of program literature and consultation with relevant subject matter experts, Appendix A contains a review of policies and programs with the potential to directly or indirectly affect land carbon (the basis for Figure 6). These programs were then assessed for their scale of impact on various land carbon drivers. Through consultations with experts and a literature review, approaches for improving the impact and addressing the limitations of existing policies were identified.

Figure 6. Policy Impact by Land Carbon Driver



Note: This figure represents the magnitude of each land carbon driver (in MMT CO_2e, in accordance with values listed in Tables 2 and 3 – for drivers indicated by a range, this figure represents the midpoint), number of dollars leveraged by U.S. policies for each driver (x-axis), and number of acres influenced by U.S. policies for each driver (y-axis). The policy dollars and acres per driver are based on data reflected and cited in Appendix B. Red drivers decrease land carbon stock, and green drivers increase land carbon stock. Yellow drivers either lack data or the scale of their land carbon impact is highly uncertain (note that the area of these circles therefore do not correspond to a known amount of carbon gain or loss, except for "Removals" which represents the midpoint of the range presented in Table 2). "Drivers without policies/data" reflect drivers for which (1) there is no relevant policy or (2) there are no data available to understand the impact of relevant policies.

5.1. Data, Monitoring, and Projections

Data, monitoring, and projections programs generally serve three functions for the U.S. government:

- Gathering periodic data on land use and land management across the country through desk research, ground surveys, and satellite imagery analysis (National Resources Inventory, National Land Cover Database, Forest Inventory and Analysis, STATSGO)

- Translating data through a variety of models into information on land carbon stock and calculating land carbon changes over time (U.S. GHG Inventory)
- Using the above information and additional models to develop projections of land carbon changes (USGS EISA assessments, Resource Planning Act assessments)

Many U.S. agencies contribute to these programs, including the EPA, USDA, DOI, the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). Although many of these programs were not designed to produce information on land carbon, they have generated data that can help inform new policy development.

Gaps:

- ***Harmonizing and strengthening approaches to land carbon quantification:*** Discussions with expert reviewers indicate that data, monitoring, and projection programs should be closely reviewed for consistent and valid handling of assumptions and for quality of data.

5.2. Conservation

Dozens of federal conservation programs have the potential to affect land-use and management decisions. Most of these programs provide technical support, financial support, or both for implementing conservation practices on public and private U.S. land. Many of these activities may result in land carbon sequestration benefits, although they are not identified as a priority for most programs.

Many of these programs are authorized under the Farm Bill and are funded for five-year intervals. Some do not survive the Farm Bill renewal process; under the 2014 Farm Bill, the Forest Land Enhancement Program, the Wetlands Reserve Program, and Wildlife Habitat Incentives Program were not renewed, although some aspects of the programs were incorporated into programs like the Conservation Reserve Program (CRP) and the new Agriculture Conservation Easement Program (ACEP). Conservation received 28 percent of all non-nutrition-related funding under the 2014 Farm Bill, totaling $28.2 billion (Lubben and Pease 2014). The 2014 Farm Bill is the first in which conservation spending was cut, by $6.1 billion; budget sequestration in subsequent years could result in further cuts (NSAC 2014b).

To understand existing land carbon impacts of U.S. conservation programs, in-depth analysis of conservation practices at the state and county level would be required. Given the diversity of conservation practices eligible under these programs, such a high-level estimate of carbon sequestration impacts would be highly uncertain. The *2014 U.S. Climate Action Report to the UN Framework Convention on Climate Change* estimates that CRP and other Natural Resource Conservation Service (NRCS) programs could contribute 60–80 teragrams of CO_2e offsets in 2015, or approximately 7–9 percent of the current total land carbon sink, although neither the source of these numbers nor the calculation approach is clear (U.S. Department of State 2014). A large majority of this impact is through EQIP, with a large number of enrolled acres, and CRP, which has many fewer enrolled acres but a more intensive conservation program (long-term and permanent easements).

A key question is whether existing programs provide the economic signal required to enhance rural land value and to overcome significant drivers of land conversion from forest, grassland, wetland, or cropland to settlements. In regions where conversion to settlement is high, particularly around major cities and metropolitan corridors, the value of urban use conversions can be 87 times higher than the value of continued forest use (Kimbell et al. 2010). Additional assessment is needed to understand financial signals required to maintain high-carbon landscapes.

Gaps:

- ***Integrating carbon into conservation funding priorities:*** Most conservation programs do not consider carbon sequestration a priority when allocating funding. The only program with carbon sequestration as an identified priority is the Healthy Forest Reserve Program, which is funded at $6 million annually. One policy option is to include carbon sequestration potential as a consideration in allocating conservation funding and to implement carbon monitoring or estimation as part of program success metrics. However, lack of data makes it unclear what kind of incremental impact these measures could have. Some have cautioned that it will be difficult to achieve the full potential of carbon sequestration through existing conservation programs (Pinchot Institute 2011).

- ***Developing models for private finance conservation:*** Federal conservation funding decreased for the first time in the 2014 Farm Bill. Yet forest and agricultural lands face increasing pressure to convert to other uses or to adopt more intensive management practices. For example, the land carbon impacts of decreased CRP enrollment are already recognized in the U.S. GHG Inventory; since 1990, cropland soil carbon has been cut in half, in large part due to the exit of two million acres from the CRP (U.S. Environmental Protection Agency 2015). Supporting conservation through private finance will be critical to avoid further decreases in the carbon sink. To proactively increase the carbon sink, strongly catalytic frameworks are needed to leverage private finance.

- ***Developing regulatory structures for private finance:*** Significantly scaling up private investment in land carbon sequestration will likely require new regulatory incentives, as highlighted in the recently announced Presidential Memorandum on Mitigating Impacts on Natural Resources from Development and Encouraging Related Private Investment (The White House 2015b).

5.3. Markets

Two sub-national programs were included in this analysis due to their potential impact on the land sector. The two largest U.S. carbon markets, the California cap-and-trade scheme and RGGI in the Northeast, have forest carbon offset protocols that support landowners in increasing forest carbon stock. Only the California program has a sufficiently high carbon price to incentivize forestry offset projects.

Also included in this analysis is the Executive Order for Planning for Federal Sustainability in the Next Decade (Executive Order No. 13693 2015), which sets goals for government sustainability and emissions reductions. It includes government procurement requirements for "BioPreferred" and bio-based products, thereby potentially affecting biomass and wood products markets. It does not deal with land carbon sequestration directly.

The Climate Bonds Initiative protocol for Agriculture, Forestry, and Other Land Use (AFOLU) projects is included in this analysis to reflect the growing interest in green bonds for leveraging private investment. Although not required by a federal policy, the protocol could support project development incentivized through other programs discussed in this report. Bonds will not be incentives for project development in themselves, but they can support growing markets if economic conditions are right. Given suboptimal carbon prices to date, very few (if any) AFOLU climate bond projects have been implemented.[1]

Gaps:

- ***Increasing cap stringency to increase carbon price:*** Increasing carbon prices under carbon-trading programs could significantly increase the number of offset projects.

- ***Increasing number of state programs supporting land carbon offsets:*** State support of land carbon offsets can help to grow an emerging market. By augmenting resources for scaling forest and agricultural practices that increase carbon storage, these programs can help to lower transaction costs and provide a stable supply of credits to potential credit purchasers.

- ***Increasing number of opportunities for crediting of carbon-beneficial activities:*** A variety of activities with the potential to increase land carbon storage are not currently covered by compliance-grade offset protocols. A primary reason is the complexity inherent in these activities, increasing the risk that

[1] Peter Browning (Ruby Canyon Engineering), in discussion with Emily McGlynn, November 2015.

carbon benefits will be incorrectly accounted for and increasing administrative costs of monitoring and verification. Rather than develop protocols for these activities, revenues from cap-and-trade programs could be recycled to support additional land sector mitigation on a practice or area basis. Doing so has the additive benefit of increasing the net mitigation potential of cap-and-trade regulation, rather than simply providing an opportunity for emitters to offset capped emissions. The Clean Power Plan and state carbon credit auction revenues could support land sector activities.

- ***Reducing risk of carbon market entry:*** Both California and RGGI programs have strict requirements for 100-year monitoring and require the offset generator to bear the risk of carbon sequestration reversals over the project period. One opportunity for enhancing the attractiveness of these programs is to create insurance programs and other approaches to reduce barriers to market entry for landowners and project developers.
- ***Developing federal incentive programs dedicated to land carbon project development and carbon credit purchase:*** The Conservation Innovation Grants (CIG) program is the only federal program that focuses in part on carbon credit development. It does not include funding for the purchase of carbon credits. A new program could be developed to support growth of the land-carbon-crediting sector while state-level carbon markets emerge.
- ***Integrating land carbon into Executive Order for Planning for Federal Sustainability in the Next Decade:*** The Executive Order could require integration of carbon optimization into federal land management plans.
- ***Building the investment case for AFOLU bonds:*** Climate and green bonds could be a useful mechanism for financing land carbon projects and projects that indirectly enhance land carbon, but there are at least two other necessary conditions for these tools to work: favorable market economics for project development and project developers sufficiently knowledgeable about the market and the intricacies of land-based projects.

5.4. Other Incentives

USDA and the Department of Energy (DOE) support programs for stimulating biomass projects and markets, along with other rural development incentives. Biorefinery loan guarantees, community grants and loans for infrastructure, and the Biomass Crop Assistance Program (BCAP) are examples of these incentives. None of these programs are directly focused on land carbon stock, but they could be modified to encourage carbon sequestration. Funding for the programs has generally decreased under each Farm Bill and often depends further on annual appropriations processes, creating year-to-year uncertainty. This uncertainty creates a difficult policy environment for potential project developers and investors. The potential for leveraging the programs, which are significant in scope and funding, warrants greater investigation.

Other incentives are crop support and commodity insurance programs. These programs affect land carbon by increasing risk of planting crops on previously untilled land. Crop support programs potentially increase the risk of cropland conversion to grassland. The Sodsaver provision of the 2014 Farm Bill reduces that risk in Iowa, Minnesota, Montana, Nebraska, North Dakota, and South Dakota.

Gaps:

- ***Integrating land carbon as a priority in incentive programs:*** Market support programs for biomass, bioenergy, and wood products could explicitly recognize land carbon enhancement as a priority when making funding decisions and could incentivize use of biomass, such as perennial grasses, that encourages carbon sequestration or that minimizes land carbon loss.
- ***Expansion of Sodsaver and other land conservation incentives:*** As suggested by many environmental and sustainable agriculture groups, the Sodsaver provision of the 2014 Farm Bill could be expanded to apply to the prairie states of Texas, Oklahoma, Kansas, and Colorado (National Sustainable Agriculture Coalition 2014a).

- ***Incorporate climate considerations into agricultural support programs:*** Agencies could account for potential climate impacts when implementing crop support programs, incentivizing practices that minimize greenhouse gas emissions and loss of land carbon.
- ***Federal incentives for high-carbon-intensity zoning:*** There is little federal oversight of local zoning ordinances, which are a significant driver of development patterns. One example of a connection between federal policy and zoning is the National Flood Insurance Program (NFIP), which requires communities to ensure adequate flood plain mapping and to avoid development in high-risk flood areas to qualify for program participation. A federal incentive analogous to the NFIP Community Rating System could be developed for communities that develop easement programs or zoning ordinances that protect high-carbon landscapes.

5.5. Tax Code

The tax code has a number of favorable provisions for forest owners, including tax credits for reforestation, tax deductions for forest management expenses, and treatment of timber income as capital gains. These tax provisions generally work together to increase the attractiveness for forest owners of keeping their land in forest, with forest conversion being a sizable driver of land carbon loss (Coulston et al. 2015). The tax code also contains some disincentives for reforestation, including treatment of forest casualty losses: landowners can deduct only the original payment for the land or the value of lost property, whichever is lower. This deduction can often be very low for family-owned and inherited forests.

Overall, federal and state tax codes can reduce the pre-tax value of private forestland by one quarter to one half, largely through tax deductions (Greene et al. 2013). One relatively easy way to increase the impact of tax deductions for forests is to continue to increase awareness among forest owners, fewer than half of whom are aware of significant forest-related tax incentives (Greene et al. 2013). Further analysis of tax programs' overall impact on the value of forestland could illuminate the potential for further enhancing that value through tax code modifications at the federal or state level.

Gaps:

- ***Addressing disincentives for reforestation:*** Reforestation disincentives could be addressed by allowing forest owners to deduct the full cost of forest losses.
- ***Developing tax incentives on the basis of land carbon:*** Currently, forest owners receive tax benefits without regard to how their land carbon is managed. Additional tax deductions targeted to carbon-beneficial activities could be put in place for forest and agricultural landowners. Such deductions could possibly be modeled on the 2008 Farm Bill's endangered species tax deduction, which provides tax benefits for landowners who implement recovery plan-recommended activities for threatened or endangered species.

5.6. Regulation

No U.S. regulations focus specifically on land carbon sequestration, but a variety of regulations have the potential to affect land carbon, including the Clean Water Act, the Endangered Species Act, the Coastal Zone Management Act, and the National Environmental Policy Act. These regulations have provisions that directly influence land management and that can result in conservation or preservation practices that have carbon sequestration co-benefits (or that could lower carbon sequestration).

Regulations nonetheless have the potential to drive large-scale private sector investment into land conservation. For example, the Clean Water Act allows for wetland mitigation banking, in which credits generated from wetlands created and protected in one location can be purchased to demonstrate compliance elsewhere. Similarly, the Endangered Species Act allows for species banks to generate and sell credits for qualifying endangered species habitat.

The Clean Water Act requires development of plans and infrastructure to manage stormwater and any other discharges coming off of large (greater than one acre) commercial development if those discharges flow to surface waters. These plans are required under the National Pollutant Discharge Elimination System (NPDES) permitting process (U.S. Environmental Protection Agency 2014b). Project developers can meet these requirements through set-asides or easements on natural landscapes that preserve the integrity of natural ecosystems to filter and manage water (Mockrin et al. 2014).

The National Environmental Policy Act (NEPA) requires that federal agencies undertake environmental assessments (EA) and environmental impact statements (EIS) to evaluate the potential environmental impacts of proposed federal actions. The White House Council on Environmental Quality (CEQ) has released draft guidance for how agencies should consider GHGs as part of this analysis, including handling of biogenic (biomass-based) emissions. Various land management agencies are developing approaches for accounting for biogenic carbon in NEPA reporting.

Other policies deal indirectly with land management, including the Renewable Fuel Standard and California's Low Carbon Fuel Standard, both of which require significant uptake of low-carbon transportation fuels. Most of this uptake is in the form of biofuels, which could drive shifts in biomass feedstock consumption and thus in land management. Both programs use lifecycle greenhouse gas assessments to calculate the net carbon intensity of biofuel pathways, including potential direct and indirect impacts on land carbon.

For biomass feedstocks that are harvested on annual cycles, which is the case for a large majority of feedstocks used for liquid fuels, the most important dynamics to understand are soil carbon leakage. However, for longer-lived biomass feedstocks, there is significant debate in the literature about appropriate accounting frameworks for the lifecycle carbon impacts of bioenergy use (Buchholz et al. 2014; Cherubini et al. 2014; Miner et al. 2014; U.S. Environmental Protection Agency 2014a). The EPA's *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources* (Biogenic Framework) has undergone rigorous scientific review and could influence future regulatory programs that require GHG evaluation of bioenergy, including net land carbon impacts.

Gaps:

- ***Elevating integration of carbon into federal land planning:*** For programs with the potential to influence management of land carbon on federal lands, particularly the Land Management Planning Rule, additional steps could be taken to encourage not only assessment of a carbon baseline and adaptation to a changing climate, but also identification of scientifically robust strategies to optimize carbon storage along with other forest management priorities. National Forests are not required to undertake this effort, nor do they have guidance for doing so.
- ***Integrating land carbon as consideration in the NPDES permitting process:*** Developers could utilize natural landscapes and easements to manage stormwater and demonstrate NPDES compliance. A careful interpretation of NPDES could be undertaken to assess the opportunities to incentivize natural landscape stormwater management and thus facilitate land carbon benefits.
- ***Implementing protections for high-carbon landscapes:*** No-net-loss and mitigation banking approaches in the Clean Water Act and the Endangered Species Act could be replicated to protect high-carbon landscapes. Primary and undisturbed natural forests, native grasslands, and other landscapes with high carbon density could be preserved, and landowners could be required to mitigate any impacts on these areas through recreation of high-carbon landscapes in the same region. The recent Presidential Memorandum on Mitigating Impacts on Natural Resources further underlines this priority (The White House 2015b). Agencies working to deliver on this memo's directives could designate high-carbon landscapes as a natural resource requiring protection.

5.7. Summary of Gaps in Existing Policy

U.S. policies that could affect land carbon are rarely focused primarily on land carbon. Although they have their own priorities and their stakeholders seek objectives other than maximizing carbon storage, they offer a variety of levers and funding that could be used to influence carbon sequestration. Maximizing the policies' land carbon sequestration potential requires addressing the gaps identified above, which involves three main efforts:

- **Plan** to maximize carbon benefits of federal decision making, employing robust frameworks for assessing impacts of activities, policies, and programs on land carbon across agencies.
- **Optimize** the carbon benefits of existing conservation and incentive programs, prioritizing land carbon for funding allocating.
- **Leverage** private capital through the development of new regulatory frameworks, primarily mitigation banking and other market-based approaches.

6. Assessing the Potential for New Policy, Programs, and Initiatives

The policy options identified in Section 5 are assessed here on the basis of their mitigation potential and feasibility.

6.1. Potential to Address Policy Gaps

To begin assessing the potential for addressing identified policy gaps, this section gauges the GHG mitigation of identified policy and practice interventions identified in Section 4. This process began with an extensive literature review of land carbon sequestration and emission reduction potential. Studies were identified for inclusion in the review using targeted keyword searches and expert consultation. All the studies included in the assessment contain both a definable policy or practice intervention and a quantifiable land use or GHG response above a business-as-usual, without-policy, or practice scenario. For each study that met this simple two-part screen, the region the policy or practice was relevant to was identified, as was the land use affected, the land-use or management driver addressed, the gap addressed, land-use effect, GHG effect, and the potential for indirect effects. When no single or range estimate could be assigned to a land-use effect, GHG effect, or possible indirect effect, a qualitative indication of potential direction (e.g., positive, negative, uncertain, no information) was indicated. When multiple studies assessed similar policies or practices, results were combined and potential effects were expressed as a range.

The resulting mitigation assessment can be found in Appendix B: Mitigation Potential of Selected Interventions. The short timeline available for producing this report did not allow for a more formalized systematic review or meta-analysis. Results should be considered indicative of mitigation potential and not construed to be an exhaustive cataloging of either available practices or mitigation potential. By cross-referencing drivers and the magnitude of existing emissions or sequestration trends (Table 2 and Table 3), policy coverage and policy gaps (Figure 6 and Appendix A), and additional mitigation potential (Appendix B), it is possible to better appreciate opportunities to increase GHG mitigation from the U.S. land carbon stock.

This initial analysis suggests that the policy actions with the greatest potential impact and the highest level of certainty include payments for forest carbon sequestration, development of low-emissions agricultural support programs, forest management on federal lands, targeted implementation of agricultural practices, and preservation of existing land uses through urban planning and other non-federal mechanisms. However, the policies and practices reviewed in Appendix B represent only a partial list of opportunities. Although this study's gaps analysis identified other potential interventions, their mitigation potential was not in all cases known, creating uncertainty about the efficacy and even the direction of impact of certain policies. These sources of uncertainty can be addressed in two ways: policy design and further analysis.

Lack of detail in policy design can create uncertainty. The potential impact of carbon-market-based policies, for example, will depend on the stringency of the emissions cap, the amount of offsets allowed in the system, and the amount of funding to support land carbon projects. Once these values are defined, estimates of mitigation potential will reflect increased certainty.

The effect of leakage, indirect land-use change, market feedbacks, and mitigation strategy interactions needs to be taken into account to understand the true scale of emissions reduction potential. Thus, any further analysis of priority policy strategies would require elaboration of policy design considerations and integrated analysis of discrete policy scenarios.

The simplified gaps analysis and mitigation potential estimates discussed above provide a foundation for development of a policy roadmap. Potential policies must also be assessed for feasibility of political and stakeholder support, costs and benefits, and complexity of design and implementation. Screening policy recommendations in this way can further narrow priorities.

6.2. Considerations for Engaging the Private Sector

Any efforts to engage the private sector in land carbon projects should account for the needs of investors and approaches for enhancement of project attractiveness. Investor considerations include level, security, and timing of financial return. Project attractiveness considerations include policy, market, or revenue-related risks. Current barriers to leveraging private investment span all these areas.

Investors in the land sector to date have been attracted to financial flows from real estate (significant upfront investment, relatively low and stable return, long time period for total return), timber (significant upfront and annual investments, zero return for long time periods, potential large return at timber sale but with sizeable environmental and market risk), and crop commodities (annual investments and returns driven by global commodity prices, government support programs, and environmental challenges). The investors already engaged in land-based activities might assign high priority to initial engagement with land carbon projects because they are generally accustomed to the types of risk and long periods of return involved in these projects. These stakeholders will be able to support further elaboration of policy design for leveraging private finance through new regulatory frameworks.

Current U.S. government programs to support private investment are focused on grants, loans, and loan guarantees, which can support project finance for projects that already have interested equity investors. The barrier to be addressed is stimulating interest from more equity investors. Therefore, to attract investment, new policy should seek to create demand for land carbon and reduce the risk of financial return for any land carbon delivered in order to attract investment and allow projects to operate over the long term.

6.3. Building on Existing Policy Recommendations

Several policy recommendations made here are aligned with and would look to build on existing land and agriculture policy initiatives. These initiatives include:

- ***USDA's 10 Building Blocks:*** In April 2015, USDA launched 10 "Building Blocks" to reduce emissions from agriculture and forestry by 120 million metric tons of CO_2e by 2025. These building blocks include promoting no-till practices, nitrogen stewardship, livestock partnerships, sensitive land (organic soils) conservation, grazing and pasture management, private forest retention, federal forest stewardship, and promotion of wood products, urban forests, and clean energy. Implementation mechanisms are under development, but the building blocks will be largely supported through existing programs. Delivery of some of the policy recommendations described above might allow building block targets to be met and exceeded.
- ***Forest-Climate Working Group (FCWG):*** The FCWG is a consortium of organizations focused on U.S. forests, conservation, and forest carbon sequestration. Its policy platform recommends continuation of funding for criteria science, data, monitoring programs; promotion of forest products, especially as construction material; maintenance and improvement of tax incentives to restore and manage private forests; retention of forests through improved federal programs, valuing of carbon storage in federal programs, and improved tax incentives; implementation of landscape-scale initiatives through landscape conservation cooperatives and climate hubs; and support of urban forestry programs. Many of the above-noted policies are closely aligned with the FCWG platform.
- ***Shaheen Bill for Forest Carbon Incentives Program:*** U.S. Senator Jeanne Shaheen of New Hampshire has introduced a bill to implement a practice-based forest carbon incentive program. Like participants in EQIP and other practice-based support programs, forest owners would receive a set dollar amount for every acre they enroll under a certain practice determined to increase forest carbon. This concept originates from a Pinchot Institute recommendation (Pinchot Institute for Conservation 2011).
- ***Coalition on Agricultural Greenhouse Gases (C-AGG):*** C-AGG seeks to improve the robustness of agricultural offset protocols and other ecosystem service markets, including the California cap-and-trade program, RGGI, and regional water trading systems. It has supported incorporation of carbon markets and land-based offsets into federal policies, including the Clean Power Plan and the Executive Order for Planning for Federal Sustainability in the Next Decade.

Although many of the policy concepts discussed in this report are not new, they deserve evaluation in the context of enhancing the land carbon sink overall and understanding the potential trade-offs and interactions across policy initiatives.

6.4. Implementation Considerations

A number of considerations should be taken into account as policy recommendations are further developed. A robust, long-term U.S. land carbon strategy would account for all of the following issues:

- ***Strategically time land carbon interventions:*** The total impact of land carbon sequestration efforts will depend, in part, on the availability of sequestration potential and the uncertainty of future impacts (Haim et al. 2014). Past analyses have shown that it may even be optimal to keep some amount of sequestration potential in reserve to be used in the event of unanticipated GHG mitigation needs and to thus avoid total sink saturation (Gitz et al. 2006). Policy makers could think about the land carbon sink as a strategic mitigation option to be managed over time, requiring development of a long-term strategy for optimizing economy-wide emissions reductions over time.

- ***Strategically target land carbon interventions:*** Limited funds require that outreach and implementation be targeted to areas with the largest potential benefit. Options for addressing this challenge include micro-targeting sites for carbon incentive deployment (Wang and Medley 2004) or including some measure of carbon benefit in existing conservation programs so as to weight the contributions of different projects or practices (Baker and Galik 2009).

- ***Prioritize certainty of policy impacts:*** As the discussion above highlights, there is significant uncertainty about many policy recommendations' scale of mitigation potential and potential for indirect or undesirable co-effects. Scenario analysis of policy design options and robust life cycle accounting of total policy impacts will be required. An economy-wide solution is unlikely at the present time, necessitating evaluation of other policy solutions in a so-called second-best setting. Research has shown, however, that second-best or other less-than-ideal policies have the potential not only to reduce the efficiency of GHG mitigation, but also to generate negative co-effects (i.e., leakage) (Rose and Sohngen 2011). There may also be trade-offs between climate mitigation and climate adaptation objectives as well as between climate mitigation objectives and other environmental outcomes of concern. As noted below, these potential trade-offs need not preclude further GHG mitigation efforts, though they may complicate their design and implementation.

- ***Optimize interactions among climate mitigation and adaptation:*** Previous research indicates potential for compounding or cross-purposing the benefits of mitigation activities and the benefits of adaptation activities in the land sector. Forests are susceptible to a variety of disturbances such as insects, fire, ice storms, windstorms, and other weather events that reduce carbon storage. Management solely for carbon can increase the vulnerability of stands to these types of disturbances (Galik and Jackson 2009; Daigneault et al. 2010). It is therefore important to maximize carbon storage in a way that also recognizes natural disturbances and even hedges against them (Galik and Jackson 2009). The capacity of agricultural systems to respond to yield shocks could also be complicated by efforts to maximize carbon storage (Pena-Levano et al. 2015). This consideration highlights the need to include the crop yield impacts of climate change when designing forest carbon sequestration programs. In summary, programs have to balance objectives in attempting to realize maximum overall carbon sequestration potential.

- ***Consider interactions among programs with different objectives:*** Policies to increase GHG mitigation on forest and agricultural lands can create both co-benefits and trade-offs with other environmental services, amenities, or objectives (Plantinga and Wu 2003; Bryan 2013). For instance, tree plantations established to sequester carbon may lead to significant decreases in streamflow and increases in soil acidity or to improvements in water quality and decreased soil salinization, depending on site conditions (Jackson et al. 2005). Potential trade-offs likewise exist between carbon and biodiversity (Nelson et al. 2008; Rittenhouse and Rissman 2012). Importantly, individual practices have the potential to both positively and negatively affect the same resource. For example, agricultural practices such as no-till farming can positively affect water quality by reducing sedimentation while negatively affecting it by potentially leading to increased herbicide use and runoff (Olander et al. 2011). These collective interactions become particularly important to consider in the context of existing federal programs, because limited and ostensibly decreasing operational budgets could create challenges to achievement of both current and new objectives like carbon storage (Jones et al. 2013).

7. Conclusions and Next Steps for Research and Application

This report has identified steps that could be taken to develop a long-term land carbon roadmap for the United States. Addressing gaps in data collection, organization, and presentation will be critical to implementing key policy recommendations.

7.1. Addressing Information and Analysis Gaps

The following recommendations address gaps in information and analysis, providing a strong foundation for policy development and decision making.

- ***Presenting carbon loss and gain according to key drivers:*** Land carbon data needs to be organized in a way that allows policy makers to understand the complete set of drivers of carbon loss and gain in a holistic and consistent way for every region. This kind of presentation can better guide policy development and support policy impact assessments. The current U.S. Forest Carbon Accounting Framework (Woodall et al. 2015) represents an important step in this direction.
- ***Consistent handling and presentation of carbon effects of mitigation strategies:*** Accounting for market dynamics and carbon leakage potential is inconsistent. These indirect effects can have a significant impact on net carbon storage at the project and policy levels (Murray et al. 2004). Accounting for land carbon interventions' direct and indirect effects could be standardized through a U.S. government process that the research community can adopt and replicate (see U.S. Environmental Protection Agency 2014a for one example of such a process).
- ***Updated, consistent mitigation potential analysis:*** Relatively little existing information supports understanding of the net potential impact of this report's suite of policy recommendations. Despite the substantial literature on carbon pricing impacts on land carbon sequestration and on individual practice-based activities, the total impact of a select subset of land carbon policies cannot be assessed with existing analysis. The total effects of indirect land-use change, leakage, market dynamics, and policy interactions are unknown. Subsequent work would aim to rigorously quantify mitigation potential.
- ***Clear explanations of major uncertainties:*** Sources of uncertainty across land carbon analysis programs include data collection gaps, algorithms for translating satellite imagery into land cover types, and modeling to convert land cover information and forest biomass data into carbon estimates. The LULUCF inventory includes uncertainty analysis, but the scope of this analysis is unclear because not all model assumptions are reported.

7.2 Immediate Priorities for Action

Developing a holistic land carbon strategy on the basis of available data is difficult. Nevertheless, several key tasks identified in this analysis could warrant immediate action:

- Optimizing patchwork of existing federal programs to support land carbon. As this report illustrates, many existing federal levers could be tailored to drive land carbon outcomes. A regional project, for example, through the Regional Conservation Partnership Program, could allow the potential of integrated carbon management through multiple federal programs to be assessed. The objective would be to demonstrate the feasibility of deploying existing programs to generate carbon sequestration and to support a rigorous theoretical process to achieve cross-cutting land carbon outcomes with existing federal resources.
- Develop forest management principles and guidance for optimizing land carbon with other management priorities. Forest management can have significant implications for the carbon sink. The impacts of a number of factors, including harvested wood products, fossil fuel offsets, wildfire risk reduction, and

indirect/market effects of reduced or increased forest removals should be assessed and integrated into sustainable forest management frameworks. Additional analysis would support full understanding of the potential impacts of any policy action for forest management and changes in carbon stock.

- Incentivizing forest regeneration and afforestation. Available data indicate that forest regeneration and afforestation currently contribute little to the carbon sink, and there is relatively little policy focus on these activities. Understanding the additional mitigation potential of afforestation and regeneration, particularly in counteracting the effect of aging forests, could address a policy gap.
- Reducing risk of forest conversion to settlement. No federal policy drivers limit forest conversion to settlement. Several policy priorities identified above, including new no-net-loss policies for forests and high carbon-intensity zoning, could help address this problem. Incremental incentive programs could have some impact but are unlikely to overcome the high value realized by converting forest to settlement.

These tasks could be implemented through regional demonstrations and individual project development in 2016 and could be implemented nationally in the longer term.

7.3. Addressing Identified Gaps and Policy Recommendations: Next Steps

To develop a long-term policy roadmap for maintaining and enhancing U.S. land carbon sequestration, the following tasks are proposed:

- ***Development and regional demonstrations of immediate action priorities:*** Leveraging existing projects and programs where possible, regional demonstrations or pilot tests of key policy recommendations can expand understanding of policy impact, scalability, and feasibility. Demonstrations would be designed to address regionally specific land carbon drivers and priorities and would be executed in cooperation with landowners, local policy makers, environmental stakeholders, and others. Private-sector investment could be emphasized to seed markets early on.
- ***Development of a holistic analytical framework:*** Historically, projections of mitigation potential have been conducted in a piecemeal fashion, providing critical information on the performance of specific programs or practices but not on the interactions of a complex array of separate initiatives. Building on existing data and analysis, a robust analytical framework could account for direct and indirect impacts and for policy interactions to indicate the policy interventions necessary to maintain and, ideally, increase the carbon sink.
- ***Further development and streamlining of policy priorities:*** Building on additional analysis and improved understanding of total mitigation potential, stakeholders, experts, and policy makers could further refine policy priorities.
- ***Detailed policy design:*** Key policy design considerations could be determined on the basis of stakeholder, expert, and policy maker consultations. This process will also help clarify the mitigation potential assessed through the updated analytical framework by better defining policy details. Private sector stakeholders and the investment community are priorities for engagement.
- ***Engagement to implement preferred policies:*** Once priority policies are chosen and policy design is elaborated, stakeholders can begin outreach to implement new policies.

Appendix A: U.S. Land Carbon Policy and Program Inventory

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Data, Monitoring, Projections, and Awareness							
Forest Inventory and Analysis National Program	USFS	McSweeney-McNary Forest Research Act of 1928; 1998 Farm Bill (renewed 2014)	Baseline calculations and projections of U.S. forest carbon (public and private)	$70 million[b]	Awareness, data	Maintain funding; begin data collection on drivers of changes in carbon stock and on end uses of harvested material	N/A
National Land Cover Database	USGS	N/I[a]	Baseline calculations of carbon on all U.S. land types	N/I	Awareness, data	Maintain funding; develop baseline and projections for interior Alaska to understand impact on land carbon trajectory	N/A
National Resources Inventory	NRCS	Rural development Act of 1972; RCA of 1977	Baseline calculations of carbon on non-federal U.S. land types	$35 million[c]	Awareness, data	Maintain funding	N/A
Soil Survey Programs (Web Soil Survey, STATSGO)	NRCS	1896 ongressional Act	Provides data for use in soil carbon calculations for inventory and projections	$80 million[d]	Awareness, Data	Maintain funding	N/A
National Forests Climate Scorecardf	USFS	N/I	Greater awareness and capacity to address land carbon issues on national forests; establishing carbon baselines for all national forests	$1 million[e]	Awareness, Data	Implement; ensure that data on carbon stocks can influence budgets and priority areas for restoration and deforestation; ensure data can be reflected in EPA GHG inventory process	N/A
National Forest System Carbon Assessment	USFS	N/I	Understanding dynamics in federal forests that drive carbon gain or loss	N/I	Awareness, data	Assessment of feasibility of using this information to avoid carbon loss on public land; identification of next steps for understanding impacts of disturbances (fire, insects)	N/A

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
U.S. GHG Inventory	EPA	UNFCCC, IEA, others	Demonstrating compliance with domestic and international climate targets, including land sector contribution	N/I	Awareness, data	See Appendix D: Planned Improvements in the National GHG Inventory	N/A
USGS EISA Assessments	USGS	N/I	Projection of carbon stock on all U.S. land types to 2060	$78 million[g]	Awareness, data	Improved coordination with related initiatives: Resource Planning Act, U.S. Biennial Report	N/A
Climate Hubs	USDA	Executive authority, Climate Action Plan	Implementing mechanism for Climate Action Plan in agriculture, forestry	$120 million[h]	Awareness, data	Additional information on how Hubs are translating into action on the ground relative to a business-as-usual scenario; understanding impacts of information sharing	N/A
Agricultural and Food Research Initiative (AFRI)	USDA	2008 Farm Bill	Part of program supports activities that increase carbon sequestration, largely through new research and modeling tools	$39 million[i]	Awareness, data	Inconsistent annual funding; focus on scalable opportunities	N/A
Forest Products Laboratory	USFS	N/I	Conducts research to support conservation and productivity of forest resources (uptake of forest products)	N/I	Awareness, data,	Inconsistent annual funding; focus on scalable opportunities	N/A
Climate Change Response Frameworks	USFS orthern Research Station and Eastern Region	N/I	Develops regional climate adaptation plans for private and public forests in the northern and eastern regions	N/I	Awareness, climate	Increased focus on sequestration	246 million
America's Great Outdoors Initiative	DOI	N/I	Develops strategic plans for five "demonstration landscapes"	N/I	Awareness, restoration, conserva-tion	No explicit prioritization of carbon sequestration in strategic plans	N/I
Landscape Conservation Cooperative National Council	DOI	Secretarial Order 3289, 2010	Interagency and multi-stakeholder cooperative to enhance conservation and climate resiliency on public lands	N/I	Awareness, restoration, conserva-tion	N/I	N/I

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Climate Science Centers	DOI	Secretarial Order 3289, 2010	Research for ecosystem, landscape monitoring and modeling	$27 million[j]	Awareness, data	Could be tasked to answer key questions from this initiative	N/A
Forestry Products Advanced Utilization Research Initiative	USDA	2014 Farm Bill	Research funding for improving wood quality for advanced and innovative end uses	$7 million[k]	Awareness, data	N/I	N/A
Land Management Planning Rule	USFS	National Forest Manage-ment Act, Multiple-Use Sustained Yield Act, Endangered Species Actl	Monitoring carbon baseline on federal forests	$184 million[m]	Awareness, data, removals	No template yet developed for how to develop the baseline and no guidance on how to ensure carbon is optimized with other land opportunities	148.8 million[n]
Conservation							
Presidential memo-randum: Mitigating Impacts on Natural Resources from Development and Encouraging Related Private Investment	Multiple	N/A	Directs agencies to utilize mitigation banking and other strategies that leverage private investment to protect natural resources - an effort that could emphasize land carbon	N/I	Multiple	Carbon is not mentioned as a priority natural resource; unclear how this mandate will be interpreted by federal agencies	N/I
Environmental Quality Incentives Program	NRCS	1996 Farm Bill (renewed 2014)	Supports large variety of conservation activities on private land through financial and technical assistance	$1347 million[o]	Crop-to-grassland conversion, no-till farming, corn/soy rotation, urea, lime, summer fallow	Does not prioritize applications by potential carbon sequestration; no provisions for monitoring carbon sequestration impacts Improved collaboration with private sector to support investment case for healthy forests and increasing carbon stocks	N/I
Agriculture Conservation Easement Program	NRCS	2014 Farm Bill	Protects lands for agricultural use and wetlands under long-term/permanent easement	$394 million[q]	Conser-vation easement (wetlands, grassland)		N/I
Conservation Stewardship Program	NRCS	2008 Farm Bill (renewed 2014)	5-year contracts for incremental improvements in conservation practices on enrolled acres	$1158 million[s]	Same as EQIP		N/I

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Healthy Forest Reserve Program	NRCS	Healthy Forests Restoration Act of 2003	10-year cost-share agreements, 30-year easements, or permanent easements on private or tribal forestland; must demonstrate recovery of endangered species, improve biodiversity, or increase carbon storage	$6 million	Conser-vation easements (forests)	Low funding levels, one of the potentially most important programs for forest carbon and one of the lowest-funded conservation programs; only conservation program with an explicit focus on land carbon	0.68 million[u]
Regional Conservation Partnership Program	NRCS	2014 Farm Bill	Organizations can compile funding from EQIP, ACEP, CSP, HFRP programs into holistic project that leverages federal funding with private investment	$93 million[v]	Same as EQIP	Does not prioritize applications by potential carbon sequestration; no provisions for monitoring carbon sequestration impacts	N/I
Conservation Reserve Program (and Conservation Reserve Enhancement Program)	FSA	1985 Farm Bill (renewed 2014)	10- to 15-year easements for taking agricultural land out of production and re-establishing native plant cover	$1808 million	Conser-vation easements (grassland), crop-to-grassland conversion	Maximum enrollment cut from 32 million acres to 24 million acres in 2014 Farm Bill in 2017/2018	24 million[w]
Emergency Forest Restoration Program	FSA	U.S. Troop Readiness, Veterans' Care, Ka-trina Recov-ery, and Iraq account-ability propriations Act, 2007	Assists landowners to restore/enhance forestland damaged by 2005 hurricanes Dennis, Katrina, Ophelia, Rita, and Wilma under 10-year contracts	$6 million	Regenera-tion, affor-estation	Decreasing levels of funding due to narrow program mandate; interesting model for addressing ongoing forest restoration needs for wildfire, disease, infestation	0.025 million
Landscape-Scale Restoration	USFS	N/I	Allows states to utilize combination of funding from Forest Health Management, State Fire Assistance, Forest Stewardship, Urban and Community Forestry programs for innovative projects	$24 million[x]	Regenera-tion, affor-estation, wildfire, insects/dis-ease	Improved collaboration with private sector to support investment case for healthy forests and increased carbon stocks	N/I
Forest Stewardship Program	USFS	Cooperative Forestry Assistance Act of 1978	Assistance to forest owners for enhancing long-term productivity and forest resources	$22 million[y]	Conserva-tion, affor-estation	Declining funding at state and federal levels	34 million[z]

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Forest Legacy Program	USFS	1990 Farm Bill (renewed 2014)	Supports states in purchasing private forests and putting them under permanent easement	$51 million[aa]	Conserva-tion Ease-ment	N/I	2 million[bb]
Community Forest Program	USFS	2008 Farm Bill (renewed 2014)	Grants to support establishment of community forests	$2 million[cc]	Afforesta-tion	N/I	N/I
Urban and Community Forestry Program	USFS	1990 Farm Bill (renewed 2014)	Tree planting initiatives in urban areas	$24 million[dd]	Urban trees	N/I	N/A
Forest Health Management Program	USFS	N/I	Monitors and assesses national forest health and provides funds for forests at risk of wildfire, disease, infestation	$105 million[ee]	Data, wildfire, insect, disease	N/I	N/I
Collaborative Forest Landscape Restoration Program	USFS	Public Land Manage-ment Act of 2009	Competitively funds projects for hazard-ous fuel reduction, maintenance of old-growth stands, improvement of wild-life habitat, removal of invasive species, avoidance of road construction, on high-priority land-scapes[gg]	$90 million[ff]	Conser-vation, wildfire, reduced harvest	Focus on avoided conversion of forests to settlements or other land uses in high-priority landscapes	0.58 million
Land and Water Conservation Fund	DOI	Act of Congress 1965	Uses offshore oil and gas revenues to support acquisition of new federal land for national parks, forests, community projects	$248 million[hh]	Conser-vation easements (grassland, wetland, forest)	Fund authoriza-tion lapsed in September 2015; significant source of funding, not from tax payers, that could be used to prioritize land carbon ac-tivities on existing and new federal land	5 million[ii]
Longleaf Pine Initiative	NRCS	N/I	Seeks to restore 4.6 million acres of longleaf pine on public and private lands in the Southeast by 2025	$12 million[jj]	Removals, conserva-tion ease-ment	Longleaf pine may exhibit lower standing carbon than managed stands, but bio-diversity benefits are significant; handling of such trade-offs remains to be determined	0.26 million[kk]

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Partners for Fish and Wildlife	FWS	Partners for Fish and Wildlife Act of 2006	Financial and technical assistance for private landowners to improve habitat and ecosystems	$52 million[ll]	Conser-vation easements (wetland, grassland, forest)	Does not prioritize applications by potential carbon sequestration; no provisions for monitoring carbon sequestration impacts	0.46 million[mm]
Federal Wildland Fire Policy	USFS	N/I	Interagency program to address wildland fires	$1400 million[nn]	Thinning, wildfires, re-generation	N/I	676 million[oo]
Conservation Innovation Grants	USDA	2014 Farm Bill	Encourages creative projects for con-serving ecosystem services, including carbon storage	$20 million[pp]	Conser-vation easements, same as EQIP	N/I	N/I
Markets							
Regional Greenhouse Gas Initiative (RGGI)	RGGI, Inc.	Member State Statutes	Nine Northeast states' regional emissions cap-and-trade program; offsets, including forest carbon, can meet up to 3.3 percent of each state's obligation; forest offsets can be generated from reforestation, improved management, and avoided conversion	N/I[qq]	Bioenergy, land value (forests)	Afforestation is only credited in CT and NY; Ex-pand offset caps; low credit price ($6/ton) has yet to generate forestry projects; credit price predicted to reach $10/ton in 2020, at which point it could be attractive and sim-ilar to credit price in CA;[rr] assess po-tential to support land carbon from auction revenues	N/A
California Cap-and-Trade	California Air Re-sources Board	California AB 32	Allows for reforestation, improved management, and avoided conversion forest offsets; first forestry offset project approved in 2014; 17.4 million forestry offset credits issued	$175 million[ss]	Bioenergy, land value (forests)	Expanding offset caps; assess potential to support additional land carbon sequestration through auction revenues (a portion of auction revenues are already dedicated to sustainable land management)	1.7 million[tt]
Executive Order: Planning for Federal Sustainability in the Next Decade	White House	Executive authority, 2015	Sets goals and requirements for federal government sustainability	Signifi-cant	Wood products markets	Does not deal with management of federal lands to enhance carbon sequestration; does not promote biomass-based building construction materials	640 million[uu]

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Climate Bonds Initiative, AFOLU Guidance	N/A	N/A	Provides guidance for issuing bonds for agriculture, forestry, and other land-use projects that result in carbon sequestration	N/A	Land value (forests)	N/I	N/A
Other Incentives							
BioPreferred Program	USDA	2002 Farm Bill (renewed 2014)	Sets requirements for purchasing bio-based materials and products under federal purchasing programs (for purchases greater than $10,000)	N/I[vv]	Wood products markets	Does not include timber for construction, maximizing wood use in buildings; does not apply to bio-based fuels in energy consumption	N/I
Woody Biomass Utilization Grants	USDA/ USFS	National Energy Policy Act 2005	Provides grants for projects that support wood products markets	N/I	Wood products markets	N/I	N/I
Woodworks Initiative	Wood Products Council, USDA	N/A	Seeks to develop new, growing markets for wood products	$1 million[ww]	Wood products markets	N/I	N/I
Biomass Crop Assistance Program	USDA	2008 Farm Bill (renewed 2014)	Subsidizes biomass recovery from forest and other ecosys-tems (matching pay-ments) and estab-lishment of grasses and other energy crops (establishment payments)	$25 million[xx]	Bioenergy	No prioritization approach for biomass sources that enhance land carbon stock	0.05 million[yy]
Biorefinery Assistance Program	USDA	2008 Farm Bill (renewed 2014)	Loan guarantee for biorefineries	$124 million[zz]	Bioenergy	No prioritization for biomass sources that enhance land carbon stock, although this approach could be favored in application review process	0.36 million[aaa]
Renewable and Energy Efficiency Projects Solicitation for Loan Programs Office	DOE	Energy Policy Act of 2005	Loan guarantee for biorefineries and potentially other biomass utilization facilities	$1000 mil-lion[bbb]	Bioenergy	No prioritization for biomass sources that enhance land carbon stock, although this approach could be favored in application review process	0.09 million[ccc]

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Rural and Business Development Loan Programs	USDA	Multiple	Includes business and industry guaranteed loans, Intermediary Relending Program, Rural Microentrepreneur Assistance Program, rural economic development loans/ grants, Value-Added Producer Grant, Socially Disadvantaged Groups Grant, Rural/Business Development Cooperative Grant	$1028 million[ddd]	N/I	Allow these funding programs to support development of carbon offset programs or fund purchases of carbon offsets	N/I
Renewable Energy Systems and Energy Efficiency Improvements Loans/Grants	USDA	2002 Farm Bill (renewed 2014)	Loan guarantees and grants to support landowners/ farmers in installing renewable energy and energy efficiency projects	$50 million[eee]	N/I	Develop component of REAP that prioritizes sustainable bioenergy/ biomass utilization	N/I
Advanced Biofuel Payment Program	USDA	2008 Farm Bill (renewed 2014)	Incremental payment for produced biofuels on a varying per gallon basis	$14 million[fff]	N/I	Irregular subsidy levels and short-term funding authority does not allow for market entry support for new projects; only supports existing projects	N/I
Crop Insurance Support Programs	USDA	2014 Farm Bill	Reduces risk of crop production on marginal land; potential for increasing grassland-to-cropland conversion	$8600 million[ggg]	Crop prices, grassland-to-crop conversion	N/I	280 million[hhh]
Crop Support Programs	USDA	2014 Farm Bill	Same as crop insurance support programs	$5000 million[iii]	Crop prices, grassland-to-crop conversion	N/I	390 million[jjj]
Sodsaver Provision	USDA	2014 Farm Bill	Reduces crop insurance support by 50 percent for cropland converted from native grassland; applies to six mid-western and plains states - Montana, North Dakota, South Dakota, Minnesota, Iowa, and Nebraska	N/I	Crop-to-grassland conversion	Does not apply to prairie states Texas, Oklahoma, Kansas, and Coloradokkk	64 million[lll]

Program	Agency	Implementing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Tax Code							
Reforestation Deduction	Treasury	U.S. Tax Code	Landowners can deduct $10,000 of reforestation costs annually and amortize additional amounts over 8 years	N/I	Afforestation	Maintain deduction; only 55 percent of polled forest owners were aware of this deductionmmm	N/I
Depreciation Deduction	Treasury	U.S. Tax Code	Forest owners can recover investments in machinery, buildings, other capital	N/I	Land Value (forest)	Maintain deduction	N/I
Depletion Deduction	Treasury	U.S. Tax Code	Forest owners can recover investment in forest as a "depletion deduction"	N/I	Land value (forest)	Maintain deduction	N/I
Forest Management Deduction	Treasury	U.S. Tax Code	Applies to forester costs, brush control, fertilization, stand improvement, insect/disease control, and other "ordinary and necessary" practices	N/I	Afforestation, land value (forest)	Maintain deduction	N/I
Tax Treatment of Forest Casualty Losses	Treasury	U.S. Tax Code	Forest owners can deduct basis (original payment for land) or loss, whichever is lower	N/I	Land value (forest)	Creates disincentive for reforestation after disturbance and losses if the land was inherited; provisions could be allowed for small family forest owners to recover forest losses; few forest owners are aware of this tax incentivennn	N/I
Capital Gains Treatment of Timber Income	Treasury	U.S. Tax Code	Timber is taxed at capital gains rate of 15 percent rather than at 35 percent tax rate for ordinary income	N/I	Land value (forest)	Maintain tax treatment	N/I
Deduction for Conservation Program Cost Share	Treasury	U.S. Tax Code	Landowners may deduct cost-share payments for CRP, EFRP, EWPP, EQIP, FHPP, LLPI, SAWE, WRP, WHIP	N/I	Conservation easement (grassland, wetland, forest)	Maintain deduction	N/I

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
State Income Tax Deduction Provisions	Multiple	Multiple	States have different approaches to taxing income from forests; forest ownership is more attractive in some states than in others	N/I	Land value (forest)	Encourage harmonization of income tax for forestland across states to enhance attractiveness of forest ownership	N/I
Use Value Assessment	Treasury	U.S. Tax Code	Agricultural land is evaluated at its current use, not for its highest possible value; creates incentive for landowners to maintain agricultural use	N/I	Land value (forest, cropland)	N/I	N/I
Regulation							
Clean Power Plan	EPA	Clean Air Act	Has the potential to create demand for sustainable biomass resources which could drive up forest value	N/I	Bioenergy	Will require close examination of sustainability requirements for biomass and emissions accounting	N/I
Renewable Fuel Standard	EPA	Clean Air Act	Creates significant demand for crops for renewable fuel and cellulosic material (wood, energy grasses, etc.)	N/I	Crop prices, productivity, land value (cropland)	RFS GHG accounting does not directly incentivize positive land carbon outcomes (unlike California Low Carbon Fuel Standard)	N/I
California Low Carbon Fuel Standard	CARB	AB 32	Creates significant demand for crops for renewable fuel and cellulosic material (wood, energy grasses, etc.)	N/I	Crop prices, productivity, land value (cropland)	N/I	N/I
Clean Water Act	EPA	Federal Water Pollution Control Act Amend-ments of 1972	Expanded protection of wetlands can increase preservation of highly carbon-dense landscapes	$3000 million[ooo]	Conser-vation easement (wetland), develop-ment	Would need to assess impact of final Waters of the U.S. rule to understand additional wetland protection impact	
Coastal Zone Management Act	NOAA	CZMA of 1972	Coastal wetland protection	N/I	Develop-ment	N/I	N/I

Program	Agency	Implement-ing Authority	Potential Impact on Land Carbon	Budget ($ mill.)	Driver of Carbon Gain/Loss	Carbon Sequestration Gap framework(s)	Acres Affected (m, annually)
Endangered Species Act	FWS	ESA of 1973	Strong driver of land management and preservation activities where there are endangered or threatened species and/or their habitat	N/I	Devel-opment, land value (forest, cropland), reduced harvest	N/I	0.16 million[ppp]
National Environmental Policy Act (NEPA), Environmental Impact Statements	Multiple	National En-vironmental Policy Act of 1970	Requires examination of environmental impacts of any federal investments, actions, and projects	N/I	Potentially many	NEPA EIS approaches could begin to take into account land carbon impacts and prioritize actions that have positive land carbon effects; CEQ has released draft guidance that would encourage this effort, agencies working to address this	All U.S. acres
National Flood Insurance Program	FEMA	National Flood Insurance Act of 1968	Example of federal incentives guiding local planning processes	$3500 million[qqq]	Develop-ment, land value (set-tlement)	N/A	N/I

[a] N/I = No information
[b] U.S. Department of Agriculture (2015c), p. 77.
[c] Government Accountability Office (2005), p. 45. Latest data comes from Conservation Technical Assistance budget.
[d] U.S. Department of Agriculture (2015c), p. 68.
[f] U.S. Forest Service (2012b).
[e] Approximation. Funding is opportunistic at federal level; regional USFS offices may also contribute.
[g] U.S. Department of the Interior (2015b), p. 154 (Totals for Land Remote Sensing and Land Change Science).
[h] At least $120 million. Johnson (2014).
[I] $5 million for carbon sequestration activities; $34 million in FY15 for sustainable bioenergy; does not represent consistent annual budget; U.S. Department of Agriculture (2015a); U.S. Department of Agriculture (2015b).
[j] U.S. Department of the Interior (2015b), p. 154.
[k] U.S. Department of Agriculture (2014b).
[l] 77 Fed. Reg. 21162; April 9, 2012.
[m] U.S. Forest Service (2014b).
[n] U.S. Forest Service. (2015d).
[o] U.S. Department of Agriculture (2015c), p. 68.
[p] Pinchot Institute for Conservation (2011).
[q] U.S. Department of Agriculture (2015c), p. 68.
[r] Weller (2015).
[s] U.S. Department of Agriculture (2015c), p. 68.
[t] Weller (2015).
[u] Natural Resources Conservation Service (2015b).
[v] Also supported by funding from supportive NRCS programs (EQIP, ACEP, etc.); U.S. Department of Agriculture (2015c), p. 68.
[w] Reflects statutory limit from 2014 Farm Bill.
[x] U.S. Department of Agriculture (2015c), p. 77.
[y] U.S. Forest Service (2014b), p. 45.

[z] Pinchot Institute for Conservation (2011).
[aa] U.S. Forest Service (2014b), p. 45.
[bb] Pinchot Institute for Conservation (2011).
[cc] U.S. Forest Service (2014a).
[dd] U.S. Forest Service (2014b), p. 24.
[ee] U.S. Forest Service (2014b), p. 17.
[gg] U.S. Forest Service (2015a).
[ff] U.S. Forest Service (2015a), p. 13.
[hh] Authorized at $900 million but most funds are allocated to other budget items (Land & Water Conservation Fund Coalition 2014); see also Theobald (2015).
[ii] Land & Water Conservation Fund Coalition (2015).
[jj] Natural Resources Conservation Service (2015a), p. 1.
[kk] Natural Resources Conservation Service (2015a).
[ll] U.S. Department of the Interior (2015a), p. 35.
[mm] U.S. Fish and Wildlife Service (2015b).
[nn] National Interagency Fire Center (2009).
[oo] National Interagency Fire Center (2015b).
[pp] Weller (2015).
[qq] No forestry offset projects yet implemented for RGGI market.
[rr] C2ES (2013).
[ss] Assuming an average offset price of $10 (discounted to current credit prices) for 17.4 million credits issued 2014–2015. This revenue is likely to increase with increasing carbon prices and a decreasing emissions cap (California Air Resources Board 2015b; California Air Resources Board 2015a).
[tt] Finite Carbon California Forest Carbon Offset Projects, Poster, 2015.
[uu] Gorte, Hardy-Vincent et al. (2012).
[vv] Federal spending could be significant, but there is no publicly available data on how much federal spending meets BioPreferred criteria.
[ww] Federal Register, Vol. 80, No. 202 / Tuesday, October 20, 2015, p. 63499
[ww] Rand (2014).
[xx] Farm Service Agency (2015).
[yy] U.S. Department of Agriculture (2015e).
[zz] U.S. Department of Agriculture (2015c), p. 41.
[aaa] Assuming approximately 30,000 acres per project reaching advanced stages of negotiation or finalization of guarantees with USDA.
[bbb] Total loan authority is $4 billion; this level assumes no more than a quarter of the program would support bioenergy-related projects.
[ccc] Assuming approximately 30,000 acres per project reaching advanced stages of negotiation or finalization of guarantees with DOE.
[ddd] $920 million is from Business and Industry Loan Guarantees; U.S. Department of Agriculture (2015c), p. 40–41.
[eee] U.S. Department of Agriculture (2015d).
[fff] U.S. Department of Agriculture (2015d).
[ggg] FAPRI (2015).
[hhh] Lynch and Bjerga (2013).
[iii] FAPRI (2015).
[jjj] U.S. Environmental Protection Agency (2015).
[kkk] National Sustainable Agriculture Coalition (2014a).
[lll] National Wildlife Federation (2015).
[mmm] Greene, Straka et al. (2013).
[nnn] Greene, Straka et al. (2013).
[ooo] Fred Danforth (Ecosystem Investment Partners), in discussion with Emily McGlynn, October 2015.
[ppp] U.S. Fish and Wildlife Service (2015a).
[qqq] Funded through premiums and fees from insured parties (U.S. Department of Homeland Security 2013).

Appendix B: Mitigation Potential of Select Interventions

The following table presents the mitigation potential of select Interventions. "Potential effect" columns are color coded to suggest the direction of effect. Red shading represents a negative land-use or GHG impact (i.e., increased emissions/reduced sequestration), yellow shading represents an uncertain range of effects, and green shading represents a positive land-use or GHG impact (i.e., decreased emissions/increased sequestration). Where available, indicative estimates of mitigation potential are provided.

Policy Option	Region	Land Use	Gap Addressed	Potential Effect (acres)	Potential Effect (GHG)	Potential Indirect Effects	Notes
Expanded Bioenergy Markets	National	Multiple	Leverage		-37–96 $MtCO_2e$/yr		GHG benefits depend on scope of program, assumed feedstock, sourcing and conversion restrictions, and inclusion of offset emission components. See Daigneault et al. (2012); Galik et al. (2015); Latta et al. (2013); White et al. (2013).
Expanded Wood Products Markets	National	Forest	Leverage		N/I		LCA studies of forest product substitution suggest substantial GHG mitigation potential on a unit-by-unit basis (20–50% as compared to a steel- or concrete-built structure), but have not assessed the implications of market responses to policy changes. See Lippke et al. (2011); Sathre and O'Connor (2010); Upton et al. (2008).
Young Farmer/ Forester Programs	National	Multiple	Leverage		N/I		Although not directed to management of GHGs, reduced burdens to professional establishment (such as targeted education or finance programs) can help maintain current use. See, e.g., Zeigler (2000).
Adoption of Agricultural Practices	National	Cropland	Optimize	N/A	-237–587 $MtCO_2e$/yr		The range represents 10th and 90th data percentiles, multiplied by maximum applicable area as reported by Eagle and Olander (2012), Table 4.
Carbon Incentive Program	National	Forest	Optimize		34–195 $MtCO_2e$/yr		Estimates the range of mitigation achieved from a voluntary program forest set-aside program (\$5–\$30/tCO_2e) as assessed by Nepal et al. (2013) and Latta et al. (2011).
Carbon Price: Afforestation	Northeast	Forest	Optimize		N/A		Estimates the range of mitigation achieved from afforestation activities at carbon prices ranging from \$5/tCO_2e to \$30/tCO_2e as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Afforestation	Southeast	Forest	Optimize		0–241 $MtCO_2e$/yr		Estimates the range of mitigation achieved from afforestation activities at carbon prices ranging from \$5/tCO_2e to \$30/tCO_2e as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Afforestation	Great Plains	Forest	Optimize		2–177 $MtCO_2e$/yr		Estimates the range of mitigation achieved from afforestation activities at carbon prices ranging from \$5/tCO_2e to \$30/tCO_2e as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).

Policy Option	Region	Land Use	Gap Addressed	Potential Effect (Acres)	Potential Effect (GHG)	Potential Indirect Effects	Notes
Carbon Price: Afforestation	West	Forest	Optimize		0–16.5 $MtCO_2e$/yr		Estimates the range of mitigation achieved from afforestation activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Agricultural Soil	Northeast	Cropland	Optimize		-4–7 $MtCO_2e$/yr		Estimates the range of mitigation achieved from agricultural soil management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Agricultural Soil	Southeast	Cropland	Optimize		1–8 $MtCO_2e$/yr		Estimates the range of mitigation achieved from agricultural soil management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Agricultural Soil	Great Plains	Cropland	Optimize		98–152 $MtCO_2e$/yr		Estimates the range of mitigation achieved from agricultural soil management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Agricultural Soil	West	Cropland	Optimize		9–13 $MtCO_2e$/yr		Estimates the range of mitigation achieved from agricultural soil management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Latta et al. (2011) and Alig et al. (2010).
Carbon Price: Forest Management	Northeast	Forest	Optimize		2–24 $MtCO_2e$/yr		Estimates the range of mitigation achieved from forest management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Haim et al. (2015), Latta et al. (2011), and Alig et al. (2010).
Carbon Price: Forest Management	Southeast	Forest	Optimize		99–255 $MtCO_2e$/yr		Estimates the range of mitigation achieved from forest management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Haim et al. (2015), Latta et al. (2011), and Alig et al. (2010).
Carbon Price: Forest Management	Great Plains	Forest	Optimize		-2–9 $MtCO_2e$/yr		Estimates the range of mitigation achieved from forest management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Haim et al. (2015), Latta et al. (2011), and Alig et al. (2010).

Policy Option	Region	Land Use	Gap Addressed	Potential Effect (Acres)	Potential Effect (GHG)	Potential Indirect Effects	Notes
Carbon Price: Forest Management	West	Forest	Optimize		6–27 $MtCO_2e$/yr		Estimates the range of mitigation achieved from forest management activities at carbon prices ranging from $5/$tCO_2e$ to $30/$tCO_2e$ as reported in Murray et al. (2005), Table 4-A-3. See also Haim et al. (2015), Latta et al. (2011), and Alig et al. (2010).
Integrated Carbon Policy	National	Multiple	Optimize	3.3–15.4 million ha (cumulative 2010–2050)	268–379 $MtCO_2e$/yr		Annual average of reported years, 2010–2050, unless otherwise noted. Range includes carbon price of $25/$tCO_2e$ alongside fixed land-use allocations, reduced BAU rate of urbanization, and both reduced urbanization and fixed land use (Alig et al. 2010).
Reduced Public Forest Harvest	National	Forest	Plan	N/A	62–105 $MtCO_2e$/yr		Assumes cessation of timber harvests on U.S. public forestlands. See Depro et al. (2008). See also Im et al. (2010).
"Climate-Smart" Support Programs	National	Cropland	Preserve		0–387 $MtCO_2e$/yr		Callaway and McCarl (1996) suggest that implementation of a no-regrets carbon payment to replace existing farm support programs could achieve carbon sequestration of up to 105 MtC/yr at a federal cost savings of ~$6.2 billion/yr while holding total welfare constant.
Development of Carbon Easements	National	Forest	Preserve		Will depend on alternative land-use and indirect effects		Expands eligibility criteria to include easements established for the express purpose of storing carbon. Aaronson and Manuel (2008) suggest that present IRS regulations may not allow for easements to be used strictly for carbon benefits. See also D'Amato et al. (2010).
Expanded Sodsaver Provisions	Great Plains	Grassland	Preserve	3% of grassland			Miao et al. (2012) suggest that up to 3% of grassland in the Prairie Pothole Region would not have been converted if federal crop insurance support was unavailable. See also Lark et al. (2015).
Forest Retention Requirements	National	Forest	Preserve				State-level forest retention and replanting requirements in Maryland were found to be effective in reversing observed forest cover losses for parcels with 0–60% cover (Ferris and Newburn 2014).
Preferential Tax Programs	National	Forest	Preserve		N/I		Enrollment in programs that grant preferential tax treatment to forest landowners is high in the western and Great Plains regions of the country, but less so in the Lake States, the Northeast, and the Southeast. See Butler et al. (2012) and Bailey et al. (1999).
Limited Land-Use Transition	National	Forest	Preserve	0.07 million ha/yr	29 $MtCO_2e$/yr		Annual average of reported years, 2010–2050. Assumes a fixed allocation of land uses over time (Alig et al. 2010).
Reduced CRP Reversion	National	Cropland	Preserve	0.9 million ha/yr	15 $MtCO_2e$/yr		Annual average change of reported years, 2005–2035. Assumes that up to 22 million acres of land that would have been reverted is maintained in CRP (Barker et al. 1995).

Policy Option	Region	Land Use	Gap Addressed	Potential Effect (Acres)	Potential Effect (GHG)	Potential Indirect Effects	Notes
Reduced Property/ Estate Taxes	National	Multiple	Preserve		N/I		Although not directed to management of GHGs, reduced disincentives for maintaining current use (such as reduction of estate taxes) can reduce conversion to other uses. See, e.g., Butler et al. (2012).
Reduced Urban Growth	National	Forest	Preserve	0.1 million ha/yr	24 Mt-CO_2e/yr		Annual average of reported years, 2010–2050. Assumes that BAU rate of development is reduced by half (Alig et al. 2010).
Carbon-Targeted Programing	National	Cropland	Target	N/I			Increases the mitigation yielded through existing farm and conservation programs. Can target those projects/activities/areas capable of yielding cost-effective GHG mitigation. See, e.g., Wang and Medley (2004), Baker and Galik (2009), and Pinchot Institute for Conservation (2011).
Improved Rangeland Management	National	Grassland	Target	N/A	17 Mt-CO_2e/yr		Olander et al. (2012).
Wetland Restoration	National	Wetlands	Target	4 million ha	-13–28 MtCO_2e/yr		Restoration of 7–12% of grassland wetlands and 20–35% of forested wetlands could have carbon market benefits that exceed the value of both the opportunity cost of foregone agriculture as well as the cost of restoration itself. Range represents 10th and 90th data percentiles, multiplied by maximum applicable area as reported by Eagle and Olander (2012), Table 4. See also Hansen (2009).

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