Stanford Law School | Law and Policy Lab

Measuring the Carbon (and Other) Benefits of Climate-Smart Forestry Practices

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Policy Lab Participants

Instructor:

David J. Hayes	Lecturer in Law, Stanford Law School

Students:

Stephen Ferruolo	Stanford Law School, 1L
David Haines	Stanford Law School, 1L
Katelyn McEvoy	Stanford Law School, 3L; Stanford Doerr Sustainability School Masters program in Environment & Resources
Leona Neftaliem	Stanford Doerr Sustainability School PhD candidate in Environment & Resources
Lia Roberds	Stanford Graduate School of Business; Stanford Doerr Sustainability School Masters program in Environment & Resources
Siddharth Sachdeva	Stanford Doerr Sustainability School PhD candidate in Environment & Resources
Celina Scott-Buechler	Stanford Doerr Sustainability School PhD candidate in Environment & Resources
Angela Tsao	Stanford Doerr Sustainability School PhD candidate in Environment & Resources
Katie Vogelheim	Stanford Distinguished Careers Institute (DCI)
Brad Ward	Stanford Graduate School of Business
Callie Walker	Stanford Law School, 2L
Benjamin Zehr	Stanford Doerr Sustainability School Masters program candidate in International Policy, Environment & Resources

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I. EXECUTIVE SUMMARY

Through nature's extraordinary process of photosynthesis, forests across the globe are capturing and storing enormous quantities of the excess carbon in the atmosphere that are causing climate change. Recent studies indicate that the world's forests sequestered about twice as much carbon dioxide as they emitted between 2001 and 2019 — forming a "carbon sink" that absorbs a net 7.6 billion metric tons of carbon dioxide per year, 1.5 times more carbon than the United States emits annually.[1] This is why trees and forests are one of the world's most valuable weapons in the fight against climate change — and why so much attention is directed at stopping the widespread deforestation underway in a number of nations.[2]

What is known, and what is knowable about U.S. forests. We know that U.S. forests are major contributors to the fight against climate change and that they are poised to do more. Even though forests are under significant stresses from climate-infused catastrophic wildfires, insect infestations and long-term drought,[3] U.S. forests are annually removing and storing the equivalent of 10 to 15 percent of overall U.S. greenhouse gas emissions.[4] Contributions are coming from the most obvious forest sources, such our National Forests, National Parks, and other federal, state, tribal and local forest preserves.[5] But they are also coming from the five billion trees and more than 100 million acres of tree cover in U.S. cities and towns[6] and the billions of additional trees that are spread throughout America's farms and pasture lands.[7]

As described more fully below, we also know that pursuing "climate-smart" forestry practices like reforestation, integrating more trees in cropland and pasture lands (agroforestry), and expanding urban forests will capture and sequester more carbon in trees. And we know that climate-smart forestry practices typically provide additional valuable services beyond carbon removal. They filter clean water for communities, provide wildlife habitat, promote biodiversity, and increase the resilience of landscapes in the face of extreme heat, drought, floods and other climate-related impacts.[8] Finally, we know that wildfires and other disasters can strike forests and cut off these benefits, pending regeneration through natural or assisted means.

However, what we do not know with confidence is ***how much*** and for ***how long*** pursuing climate-smart forestry practices will remove additional carbon from the atmosphere and sequester it in trees and in wood products. But this information is ***knowable***. Current forestry data sets — including the Forest Service's valuable FIA (Forest Inventory & Analysis) data system — are poised to sync up with powerful new remote sensing capabilities, machine learning and sophisticated modeling and data management tools to generate solid estimates of how much additional carbon is being captured through climate-smart forestry practices.

The opportunity. As described below, significant new federal funding and authority that is now available provides an unprecedented opportunity for the U.S. government to work with experts from government and the private sector to develop a suite of measurement, monitoring, reporting and verification (abbreviated herein as "MRV" or "measurement and monitoring") tools that can convert ***knowable*** climate-smart forestry benefits into confirmed, ***known*** benefits. With the backing of solid measurement and monitoring, governmental authorities and private parties can more confidently incentivize climate-smart forestry practices through a variety of potential mechanisms such as conservation grants, procurement preferences, premium pricing for climate-smart forestry products and better functioning carbon markets.

More specifically, with modern measurement and monitoring tools, baseline conditions and "additional" carbon captured and stored through deployment of climate-smart forestry practices can be identified. Likewise, improved monitoring can address so-called "permanence" issues by confirming that atmospheric removals of carbon are remaining stored in forests over defined time periods that can extend for decades, and potentially longer. And, regardless of whether those removals remain in place a hundred years from now, there may be compelling climate reasons to incentivize additional carbon removals from the atmosphere over the critically important transition period, when legacy fossil fuel use is continuing to pump excess carbon dioxide and other greenhouse gas ("GHG") pollutants into the atmosphere.[9]

As with other nature-based solutions, however, climate-smart forestry practices need not be incentivized based on carbon benefits alone. Climate-smart practices' co-benefits like clean water, biodiversity, and increased resilience to heat, drought, floods and other impacts can and should provide additional support for incentivizing climate-smart forestry practices.

Report organization. Section I of the report describes the recent Administration and Congressional initiatives that provide an unprecedented opportunity to measure and monitor the benefits that flow from investing in climate-smart forestry practices. Section II provides technical recommendations to expand carbon measurement and monitoring tools. In particular, Forest Service's FIA data protocols should be expanded and updated so landowners can be rewarded for the carbon benefits that their investments in climate-smart forestry practices are generating. Section III reviews and provides additional background and recommendations regarding how to measure, monitor and incentivize increased carbon removals and other co-benefits for six key climate-smart forestry-related practices: agroforestry, reforestation, urban forestry, improved forestry management, long-lived wood products, and bioenergy with carbon capture and storage (BECCS).

The Bezos Earth Fund commissioned preparation of this report with David J. Hayes in cooperation with Stanford Law School's Law & Policy Lab. The report is the product of an interdisciplinary policy practicum conducted with graduate students at Stanford University under the auspices of Stanford Law School.

Key recommendations.
The U.S. Department of Agriculture (USDA) and the U.S. Forest Service (Forest Service) should make a strong push to significantly improve the measurement and monitoring of carbon sequestration in U.S. forests by:

- Enhancing and expanding the Forest Service's FIA program through: (1) the cost-effective application of new technologies that will increase the scope and frequency of the program's field plot measurements; and (2) the deployment of remote sensing and machine learning capabilities to generate evidence-based, verifiable estimates of carbon sequestration in U.S. forests. These tools should be used to measure and monitor the carbon benefits of climate-smart forestry practices that are known to accumulate carbon, such as those reviewed in this report. As a corollary, the NRCS should adopt MRV-calibrated models to quantify the carbon benefits for specific climate-smart forestry practices, drawing on expertise developed by others, including the Canadian CBM.
- Coordinating with the White House, the U.S. Digital Service and outside experts to make its data on climate-smart forestry practices broadly available in anonymized, interoperable "data commons"-type formats to interested parties, and to encourage private, academic and other forestry data gatherers to do the same.

The report also identifies a number of recommendations for the USDA and the Forest Service pertinent to key climate-smart forestry practices:

- For **agroforestry**, use MRV to confirm the substantial carbon and other co-benefits associated with silvopasture, wind breaks and other agroforestry practices. Establish a strong EarthShot-type goal to expand agroforestry in the U.S. and bring coordinated and significantly expanded USDA funding and other resources to the table, including by NRCS.
- For **reforestation**, apply enhanced MRV tools to confirm carbon removals and continue to aggressively implement reforestation efforts throughout the U.S. in coordination with states, tribes, private foresters, and NGO partners.
- For **urban forestry**, utilize newly available funding to partner with local jurisdictions, NGOs and grantees to improve MRV for carbon and other co-benefits of urban tree planting that include relief from extreme heat — with an emphasis on disadvantaged neighborhoods that have limited tree cover, energy savings and urban hydrology benefits.
- For **improved forest management** ("IFM") practices such as extended harvest cycles, wildfire mitigation and forest carbon soil-related practices, develop practice-specific MRV for carbon and other co-benefits. Support the development of federal procurement standards, private certifications and financial tools to incentivize IFM practices.
- For **long-lived wood products**, commission a definitive report that addresses the relative carbon benefits of wood products as compared with other building materials. Leverage the federal "Buy Clean" procurement initiative and other mechanisms to incentivize the responsible expansion of supply and adoption of mass timber. Push certification organizations to condition their support for long-lived wood products on the confirmed deployment of climate-smart forestry practices. Support private landowners' efforts to monetize

additional carbon benefits from wood produced on their land, particularly for small, family and minority landowners.

- For **bioenergy with carbon capture and storage (BECCS**), track the potential use of forest-based feedstocks in BECCS projects for potential increases in demand for timber production to meet other needs (leakage). Consider linking the use of forestry-based feedstocks with upstream climate-smart forestry practices.

A complete list of specific recommendations made in this report is set forth in Appendix A.

II. THE UNPRECEDENTED OPPORTUNITY TO ADVANCE CLIMATE-SMART FORESTRY PRACTICES

The Administration and the Congress have new authorities and funding that make this a particularly propitious time to advance climate-smart forestry practices and to confirm the climate and other benefits that flow from the deployment of such practices. Noteworthy recent developments that illustrate Administration and Congressional support for key climate-smart forestry practices and which point to the importance of measuring and tracking the carbon and other benefits associated with such practices include:

Increased investments in USDA conservation programs. The Inflation Reduction Act (IRA) directs the Secretary of Agriculture to allocate approximately $19.5 billion in programmatic conservation spending that traditionally has been expended, in part, on conserving and expanding tree cover and other forestry-related practices that provide conservation benefits. This IRA-authorized conservation spending must be based on a Secretarial determination that the funding will "directly improve soil carbon, reduce nitrogen losses, or reduce, capture, avoid, or sequester carbon dioxide, methane, or nitrous oxide emissions." Continuous improvement in measurement and monitoring data and information are needed to support this determination for forestry-related (and other) conservation practices. Accordingly, Congress explicitly earmarked $300 million to "quantify" and "monitor and track" GHG reductions, including carbon removals ("capture" and "sequest[ration]") related to conservation practices such as reforestation and agroforestry.[10]

Increased Investments in Reforestation. The Infrastructure Investment and Jobs Act (hereinafter referred to as the Bipartisan Infrastructure Law) included the REPLANT Act ("Repairing Existing Public Land by Adding Necessary Trees"), which directed the Forest Service to plant more than a billion trees over the next decade and removed a cap of $30 million on reforestation expenditures — thereby opening up significant new funding for reforestation activities.[11] Also, the President signed Executive Order 14072 on Earth Day in 2022 which, among other things, called on the Secretaries of Agriculture and Interior to:

> "(i) develop a Federal goal that charges agencies to meet agency-specific reforestation targets by 2030, including an assessment of reforestation opportunities on Federal lands and through existing Federal programs and partnerships; [and] (ii) develop, in collaboration with Federal, State, Tribal, and private-sector partners, a climate-informed plan (building on existing efforts) to increase Federal cone and seed collection and to ensure seed and seedling nursery capacity is sufficient to meet anticipated reforestation demand."[12]

Increased Investments in Urban Forestry. The IRA appropriated a record $1.5 billion for the USDA's Urban and Community Forestry Program.[13] The USDA's initial funding opportunity called for projects to "increase equitable access to urban tree canopy and associated human health, environmental and economic benefits in disadvantaged communities . . . [and] improve community and urban forest resilience to climate change . . . through best management and maintenance practices."[14]

Increased Investments in Climate-Smart Agroforestry. In addition to qualifying under the IRA-funded conservation programs, several forestry-related projects are being funded under the USDA's $3.2 billion Partnerships for Climate-Smart Commodities initiative. Particularly noteworthy is the $60 million "Expanding Agroforestry Production and Markets" grant that is led by the Nature Conservancy. The USDA summarized the project as follows: "This project will build climate-smart markets and increase capital investments in tree planting that will increase the supply of agroforestry commodities utilizing a network of leaders in forestry. . . . Partners also aim to work with trade organizations to develop certification standards for an 'agroforestry-producers' label which will bring a price premium to producers." Also funded is a $35 million "Engaging Family Forests to Improve Climate-Smart Commodities" project led by the American Forest Foundation that seeks to generate market rewards for wood products that are produced using climate-smart practices, with a particular focus on increased participation by underserved minority and women forest owners.[15]

Increased Investments in Wildfire Mitigation Activities. The Bipartisan Infrastructure Law and the Inflation Reduction Act included a combined total of more than $7 billion for wildfire mitigation activities to reduce the frequency and intensity of wildfires. As a parallel initiative, the Secretaries of Agriculture and Interior have developed long-term plans to identify and treat forests that are at high risk for catastrophic wildfires.[16] As discussed further in this report, it will be important that federal officials assess the effectiveness of wildfire mitigation activities by analyzing reduced carbon forestry losses associated with these investments.

Increased Investments in Improved Forestry Management (IFM) practices. The Inflation Reduction Act appropriates $450 million in a new competitive grant program under the Cooperative Forestry Assistance Act of 1978 to "support the participation of forest landowners . . . in emerging private markets for climate mitigation or forest resilience." In targeting these funds toward climate-smart practices that might advance carbon markets, grantees can obtain assistance in developing and deploying measurement and monitoring tools. These tools will help quantify and validate climate benefits from improved forestry management and other climate-smart forestry practices.

Increased Support for Productive, Sustainable Forestry Activities. The President signed Executive Order 14072 in April 2022 which, among other things, called on the Secretaries of Agriculture and Interior to

> ". . . develop, in coordination with the Secretary of Commerce, with State, local, Tribal, and territorial governments, and with the private sector, nonprofit organizations, labor unions, and the scientific community, recommendations for community-led local and regional economic development opportunities to create and sustain jobs in the sustainable forest product sector, including innovative materials, and in outdoor recreation, while supporting healthy, sustainably managed forests in timber communities."[17]

In that vein, the Inflation Reduction Act included $100 million in the USDA's wood innovation grant program, including for the construction of new facilities that advance the purposes of the program and for the hauling of material removed to reduce hazardous fuels to locations where that material can be utilized.[18]

III. DEPLOYING NEW TOOLS TO MEASURE AND MONITOR CARBON GAINS FROM CLIMATE-SMART FORESTRY PRACTICES

To take advantage of the opportunity presented by the new authorities and funding identified above, the U.S. must invest in state-of-the-art GHG data collection and analysis to establish forest carbon storage baselines and track practice-based increases in storage. The Forest Service's Forest Inventory and Analysis (FIA) program provides an important foundation for this exercise, but it is currently cannot forest carbon losses and gains with adequate precision.

- **We recommend that the USDA and the Forest Service accelerate its efforts to expand the FIA program to include remote sensing and machine learning capabilities; enhance the FIA program's field plot measurements; and deploy the FIA and other appropriate data and analytical tools to measure and monitor the carbon benefits of specific forestry practices. Having stronger data confirming carbon gains from specific practices will facilitate appropriate prioritization and incentivization of such practices.**

Background. The FIA database is one of the largest natural resource datasets in the world.[19] Its key strengths lie in its long history (many permanent plots have been regularly sampled since the 1930s), robust quality assurance protocols, lack of geospatial bias (plots are distributed randomly across all US forested lands of all ownership types), and ease of use for both public and private research. In particular, the FIA program is excellent at providing national-level, point-in-time forest inventory snapshots.

Despite these strengths, however, the FIA program is not well-equipped to provide information needed for many of today's forestry data users and forestry use cases, including:

- Policymakers, landowners, and forest managers who need to understand the carbon impact of adopting different climate-smart management practices, both in the past and in the future, for their particular site type and forest condition,
- Researchers who are seeking to validate and improve forest carbon models to account for heterogeneity across the American forested landscape, and
- Carbon project developers and auditors who are working to assess additionality, verify removals, prevent leakage, and ensure permanence of their carbon projects using FIA data.

The FIA program has been successfully and ambitiously enhanced many times over its long history, notably in both the 1998 Farm Bill (which expanded sampling to include forest health measures and unified the sampling framework across all regions), and the 2014 Farm Bill (which established goals regarding urban forestry and biomass/carbon monitoring).[20]

Now, again, leaders at the USDA and the Forest Service have an important opportunity to expand and enhance the FIA program to provide a data and modeling environment that meets the needs of today's diverse forestry data users and use cases. Four target areas deserve priority attention:

Target 1: Investments in capacity for integrating new technologies, particularly remote sensing and soil sampling, to reduce costs and increase precision. Remote sensing can dramatically increase the scale, scope, and resolution of forest sampling data at relatively low cost. Yet current FIA protocols utilize remote sensing only for land cover determination, not for sampling or modeling of other characteristics such as carbon inventory.[21]

Target 2: Increasing emphasis on measuring the regional potential and field-level impacts of a wide range of climate-smart forestry *practices* for mitigating and adapting to climate change. The FIA program's plot sampling is focused on inventory and carbon outcomes, with comparatively less attention to collecting activity-based data. FIA's existing activity-focused data streams (the National Woodland Owners Survey and the Timber Products Output Survey) are too high level to contribute to detailed monitoring and evaluation of climate-smart forestry practices in U.S. forests. The FIA program should be measuring and modeling effects of practices in forestry the same way that NRCS does for agriculture.

Target 3: Supporting the development of a unified U.S. forest carbon database that is FAIR (Findable, Accessible, Inter-operable, and Reproducible). Data on carbon dynamics in U.S. forests currently exists in varied forms from diverse sources. Remote sensing data and forest plot sampling data are a prime example, but there are many others. FIA is likely the most robust forest database in existence, so it is a natural candidate to support a comprehensive public repository of forest carbon and related data. To take advantage of this important opportunity, the USDA and the Forest Service should use all available and appropriate data and analytical tools to measure and monitor the carbon benefits of specific forestry practices.

Target 4: Enabling insights at finer spatial and temporal scales. National and regional FIA carbon estimates are an important input to the U.S. National Greenhouse Gas Inventory,[22] but FIA data have limited utility at the local scale of management decision-making. Decisionmakers also need more frequent inventories of U.S. forests. Increasing sampling intensity, increasing sampling frequency, and rethinking stratification layers can help to expand the suite of use cases for FIA data.

We have several high-level recommendations in support of these target areas. They are summarized in the outline below, followed by a more in-depth discussion. In particular, the USDA and Forest Service should:

- Invest in integrating new technologies, particularly new remote sensing and soil sampling technologies, to increase the density, frequency, and comprehensiveness of the FIA data base.
- Work with NRCS to use the Canadian CBM to quantify practice-level potential and carbon impact of various climate-smart forestry practices.
- Accelerate FIA efforts to design enhanced sampling protocols that increase plot density and frequency and support fine-scale decision support.

- Coordinate with the White House and the U.S. Digital Service to integrate FIA plot data with remote-sensing and machine learning data inputs for specified climate-smart forestry practices and make this information broadly available in an anonymized format.
- Continue to innovate and emphasize collection of data beyond carbon and timber.

Each of these recommendations is considered below, in turn.

The USDA and the Forest Service should invest in integrating new technologies, particularly new remote sensing and soil sampling technologies, to increase density, frequency, and comprehensiveness of the FIA data base.

Remote Sensing

Remote sensing technologies, including optical imagery as well as active sensors such as LiDAR and radar from both satellites and UAVs, can sample at a finer scale, across a broader geographic range (including agricultural and urban landscapes), at higher return frequency, and at lower costs than ground crews. Accordingly, the Forest Service and its partners should aim to utilize remote sensing technologies to empower its workforce, to increase the frequency and density of inventories, and to reduce costs.

Recent advances in remote sensing have demonstrated that scalable, low-cost, comprehensive detection of not just tree cover but individual trees over large scales is now feasible. Researchers from the USDA demonstrated in 2016 that they could comprehensively map tree cover at high resolution for the entire state of Kansas using publicly available data from the National Aerial Imagery Program (NAIP).[23] The cost of high-resolution imagery has also dropped in cost considerably thanks to U.S.-based startups such as Planet Labs, Maxar, Digital Globe, and others. In 2019, researchers from the University of Florida showed for the first time that remote sensing could be combined with deep learning to detect individual trees at a large scale in NEON field sites.[24]

Building on this work, a paper in *Nature* published by NASA and university researchers from CTrees.org showed that deep learning methods for detection of individual tree crowns from high-resolution imagery made it possible to estimate aboveground carbon stocks of individual trees for the entire African Sahel, an area of 10 million sq. km (close to the size of the United States) with less than 20% uncertainty.[25] This advance demonstrated that individual tree inventories are feasible through automatic interpretation of optical satellite imagery with 50 cm resolution, which is freely available in the United States. Recently, researchers from CTrees showed that these methods can be combined with FIA data to dramatically improve the spatial and temporal resolution of forest monitoring data for the United States.[26]

The FIA has made significant strides toward advancing this emerging vision of remote sensing for scalable forest monitoring through their BIGMAP project, in which the Forest Service worked with Esri and Amazon Web Service to use 30 meter Landsat imagery to publish tree carbon inventory maps for the United States.[27] This body of research suggests that it is already possible to use remote sensing to monitor every tree in the United States, given currently publicly available high-resolution satellite imagery from the National Agricultural Imagery Program (NAIP), which is updated every 3 years at 50 cm resolution.

Despite FIA already having made major steps forward to advance research in remote sensing for tree inventories, these advances have not been integrated into the FIA data base. In their paper in *Forests*, leaders from the FIA wrote about three challenges that FIA has faced in operationalizing improvements from remote sensing into FIA inventories:

> "[1] After research into methods for application is conducted, it becomes clear that it is not feasible, or results are not as expected due to poorly-conceived research ideas that attempt to integrate components of many studies and stakeholder needs; [2] after prototype development, large costs of operationalization or a lack of research maturity may limit adoption likelihood; and [3] after operationalization of the technology, it becomes clear that the user community does not yet have the capacity to use the results of the new technology."[28]

Despite these challenges, the authors concluded that "NFI data are invaluable to creating RS [remote sensing] products," noting that they provide "training data for models," "increase the likelihood that RS-based estimates will align with NFI-based estimates" and "provide valuable validation data for users interested in conducting map accuracy assessments." The FIA leaders concluded that bridging the gaps constraining successful integration of remote sensing programs into FIA requires recognizing that "[a] successful RS program has access to RS data inputs, software, and hardware, including affordable high performance computing systems . . . [and that] advances in RS usage require nimbleness and outlets for creative investigation."[29]

To move forward and build on the recommendations of FIA's own leadership, we make five specific recommendations for steps that the USDA can take to realize the potential efficiency and effectiveness gains from integrating remote sensing in the FIA program and other USDA measurement and monitoring tools. Each of these is discussed in more detail in Appendix B:

1. The USDA and the Forest Service should quantify efficiency improvements from a wide variety of potential integrations of remote sensing into FIA and prioritize implementing remote sensing initiatives that promise the greatest efficiency gains. As documented in research produced by the FIA, remote sensing can drastically improve the "economic efficiency of the FIA survey [in three ways]. The first is by allowing FIA to meet NFI precision requirements with fewer field plots…. The second economic benefit of RS data integration is also related to adding value to the program, through investment in products that go beyond traditional inventory summaries and analyses…. A third benefit of RS data integration comes in the form of avoiding unnecessary field work."

2. To address the research feasibility challenges, we recommend that the USDA and the Forest Service work with CTrees.org to build on the BIGMAP project and develop code, training and evaluation datasets, pre-trained models, and scientific documentation for open-source remote sensing-based inventories of individual trees from high-resolution satellite imagery.

3. The Forest Service should anonymize, package, and distribute FIA data as the critical ground truth datasets needed by machine learning remote sensing models.

4. To address the capacity gaps in software infrastructure and remote sensing within FIA, we recommend that the USDA and the Forest Service work with the US Digital Service, hire new staff, and identify potential partners and contractors to develop the appropriate in-house capacity to make these essential improvements to the FIA inventory.

5. To address the need for nimbleness and creative investigation, we recommend that the USDA and the Forest Service invest in hosting scientific conferences and data science competitions that engage actors from private sector, academia, and public sector on new methods in remote sensing and machine learning for monitoring forests, informed by what FIA believes are the most important gaps for improving forest inventories in a changing climate.

Soil Sampling

We recommend that the USDA and the Forest Service invest in increased density of soil sampling and consider adding soil spectroscopy and sampling as part of phase 2 of the FIA plot sampling to enable measurement of soil carbon baselines as well as implications from management practices and disturbances. As noted in a recent Stanford report on Climate-Smart Agriculture:

> "New technologies and methodologies are emerging to improve carbon soil measurement and monitoring. For example, new applications of soil spectroscopy – an already well-established technology in the research domain — are generating measurements of soil carbon concentrations at a fraction of the cost of traditional analysis."[30]

Since soils sequester a significant fraction of the total carbon sequestered by forests, there is a need to significantly increase the amount of FIA's soil carbon sampling. To achieve this, we recommend that the Forest Service work with NRCS to identify and recommend protocols for performing soil sampling at 1 meter depth using soil spectroscopy and evaluate the potential of integrating new soil carbon measurement technologies to reduce costs.

Other New Technologies

We recommend that the USDA and the Forest Service invest in the development of mobile apps to support technical assistance while enabling the collection of activity data on management practices and history as well as tree biometric data from recipients of federal payments for climate-smart forestry practices. In addition to advances in remote sensing, new technologies use mobile phones. These include the popular iTree application from the Forest Service as well as innovations from startups in the carbon market and agriculture spaces. Such advancements have significantly improved our capacity to collect high quality field data both for ground truth remote sensing models as well as for monitoring variables that cannot be measured accurately enough with remote sensing.[31] Other areas outside of remote sensing that remain important investments for improving FIA methodologies for monitoring forest carbon sequestration include improving tree allometries for calculating carbon stocks and modelling attributes in forest ecosystems that we know are important for carbon but cannot be measured accurately by remote sensing approaches such as deadwood.[32]

The USDA and the Forest Service should work with NRCS to use the Carbon Budget Model of the Canadian Forest Sector (hereinafter, "Canadian CBM") to quantify practice-level potential and carbon impact of various climate-smart forestry practices.

While forest inventories and remote sensing can enable direct measurement of carbon stocks, policy and investment to support climate-smart forestry practices also requires measuring future carbon flows through modeling multiple management scenarios as well as future growth trends, while considering a wide range of sectors. Recently, researchers from Michigan State University and American Forests worked with Maryland DNR Forest Service, Pennsylvania DCNR Bureau of Forestry, and Forest Service staff to use the Canadian CBM to "assess carbon trends and management scenarios in the forest ecosystem and forest products sector . . . utilizing a systems-based approach."[33] As they summarized:

> "The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) is an operational-scale carbon model designed to simulate the dynamics of forest carbon stocks over time, following guidelines and carbon pools established by the Intergovernmental Panel on Climate Change. The model has had wide applications within Canada (Kurz et al. 2013; Kurz et al. 2018), the United States (Dugan et al. 2018; 2019; 2021), and internationally (Olguin et al. 2018; Pilli et al. 2013; 2014; 2017; 2022) while being thoroughly evaluated against ground plots (Shaw et al. 2014) and with respect to model uncertainty (Metsaranta et al. 2011; 2017). Though originally developed for Canadian forest conditions, the CBM-CFS3 is widely customizable and can be parameterized with location-specific data; for this analysis, [they] use state-specific data from the Forest Service Forest Inventory and Analysis (FIA) Program (USDA Forest Service 2019) to ensure accuracy for Pennsylvania forests. . . . The CBM-CFS3 utilizes forest inventory data and empirically-derived growth and yield curves, in combination with schedules of management activities, natural disturbances, and land-use change, to calculate forest carbon trends throughout a simulation."[34]

By using the Canadian CBM calibrated on FIA data, this team was able to quickly develop a set of statewide management scenarios for various climate-smart forestry practices and assess the systems-level carbon impacts of the scenarios.[35]

We recommend that the Forest Service work with NRCS to follow a similar process as that of Maryland and Pennsylvania to engage relevant stakeholders in integrating the Canadian CBM calibrated on FIA data for U.S. forests to quantify the potential carbon impact of a wide range of climate-smart forestry practices and prioritize public investments according to the results of that process. Given the recent funding from the Inflation Reduction Act for climate-smart forestry practices as well as a wide range of practices under NRCS that involve reforestation and/or afforestation, there is a time sensitive opportunity to achieve program alignment through collaboration across agencies and stakeholders to engage in practice-level modeling informed by different potential management scenarios for prioritizing public investments in climate smart forestry practices.

The Inflation Reduction Act allocated $450 million for grant programs to non-Federal forest landowners, $700 million for conservation of private forests through the Forest Legacy Program, and up to $1.5 billion to local government and non-profits through the Urban and Community Forestry program for climate-positive forestry activities. *Funding through these and other programs should be made contingent on grantees' utilization of strong MRV tools. And because GHG measuring and monitoring results are essential elements of funded projects, grants should require MRV and data submittals in appropriate formats that would enable their integration with a National GHG Monitoring and Information System.*

The USDA and the Forest Service should accelerate FIA efforts to design enhanced sampling protocols that increase plot density and frequency and support fine-scale decision support.[36]

We believe three dimensions of sampling design should be targeted for improvement:

1. **Sampling intensity.** The number of plots per unit area within each jurisdiction is directly related to the utility of the dataset for statistical inference on smaller and smaller subsets of the data. Doubling sampling intensity has long been a goal of the FIA, but progress has been limited due to lack of sufficient funding.[37] Similarly, while the FIA program has established a continuous annual inventory protocol, only 16% of plots are sampled each year. Finally, sampling is limited to current forested areas and largely ignores trees on agricultural lands and in urban environments (although the FIA has an urban inventory pilot program that it plans to expand).
2. **Sampling frequency.** While the FIA program samples some plots annually, allowing for reporting of annual inventory numbers, only a small percentage of plots are sampled each year, such that any single plot may not be resampled for 5 to 10 years. Increasing sampling frequency is particularly important for developing "dynamic baselines" that can help confirm that forest carbon projects produce "additional" carbon (see below).
3. **Stratification layers.** Samples are currently stratified by jurisdiction (e.g., by state), but could be more useful for management decision making if plots were allocated to forest type and/or condition or other relevant features. The current design risks under-sampling forest types that cover only a small area or that contain a higher-than-average degree of heterogeneity in their features.

Importantly, integration of remote sensing with the FIA database would improve outcomes on all three of these dimensions.

We also recommend that the Forest Service work closely with end users of the data and consider future use cases when considering adjustments to sampling protocols. As we have identified throughout this report, the use cases for high-quality forest carbon MRV are varied and continuing to expand. Critically, the use case of developing better causal inferences between carbon outcomes on the one hand and forest conditions or human activities on the other has different requirements than the use case of reporting aggregated national- or regional-level carbon stocking levels.

Dynamic baselines are an emerging best practice in determining the additionality of climate-smart forestry activities, and some protocols use FIA plots.[38] These baselines are calculations of "what would have occurred" had climate-smart management practices not been implemented on the project site. A dynamic baseline simulates a controlled experiment by comparing a project area (the experimental subject) to a composite of similar FIA plots (the control) on a regular basis over time with a goal of estimating the true "additionality" of the climate-smart management practices.

Dynamic baselines depend on frequent data refreshes in the control data from FIA plots. And while FIA conducts continuous annual sampling in aggregate, it only samples 16% of plots each year. This means that at the individual plot level, any given plot may not be resampled for 5 to 10 years. While this may be adequate for an annual report on aggregated forest inventories at the state or national level, it does not work at a project level, which requires reference to recently sampled FIA plots that are very similar to the forest type and condition of the project itself.[39]

The USDA and the Forest Service should coordinate with the White House and the U.S. Digital Service to integrate FIA plot data with remote-sensing and machine learning data inputs for specified climate-smart forestry practices and to make this information broadly available in an anonymized format.

In February 2023, the White House Greenhouse Gas Monitoring & Measurement Interagency Working Group released a draft “Strategy to Advance an Integrated U.S. Greenhouse Gas Monitoring and Information System” that identified the need for inclusion of “activity-based approaches” and of GHG monitoring of natural systems, including forests, in a national information system.[40] The FIA is well positioned as a leader in data collection and publication of forest sampling data. FIA’s DataMart platform already serves as an accessible go-to source for forest data for many relevant users throughout the U.S.

By leveraging these capabilities, partnering with relevant leaders in state forestry agencies, university research programs, private foresters, and remote sensing and other data technology experts, the USDA and the Forest Service can build out the FIA database as a more comprehensive home for greenhouse gas data from forests. This could potentially enable the USDA to play a key role in the proposed national GHG Monitoring and Information System.[41] *See* Appendix D for more discussion of relevant USDA and the Forest Service partnership opportunities.

It would be challenging for the USDA to accomplish this on its own. We recommend that the USDA and the Forest Service work with the White House, consult with the U.S. Digital Service, and explore partnering with a National Lab or another special purpose organization to make its data on climate-smart forestry practices broadly available in anonymized, interoperable “data commons”-type formats to interested parties, and to encourage private, academic and other forestry data gatherers to do the same.

The USDA and the Forest Service should continue to innovate and emphasize the collection of data beyond carbon and timber.

FIA plot samples already include valuable data on forest health, disturbances (e.g., wildfire), wildlife, and other measures. But we recognize that techniques and technology in the sampling of key forestry data points are being continuously developed. Of particular interest for MRV and research use cases are biodiversity metrics and soil carbon. Biodiversity has a host of benefits for humanity, but it also improves resilience of forest ecosystems (preventing emissions) and even is associated with greater carbon stocks (carbon removal).[42] Soil carbon is a critical — and critically understudied — carbon stock in forests that is currently difficult to measure at scale and for which remote sensing can currently offer only limited solutions. To the extent that technology and tools continue to emerge to improve MRV for these and other related data types, the FIA should work to incorporate them into its sampling protocols.

Forests also provide a wide range of other ecosystem services that need to be better measured beyond biodiversity and soil carbon.[43] These include enabling climate adaptation through reducing extreme heat and flood risk[44] as well as improving health through regulating water quality[45] and reducing air pollution.[46] FIA should continue to be a leader in improving our quantitative understanding of the wide range of benefits forests provide for people, as it is often the combination of these co-benefits with carbon sequestration that can dramatically improve the cost effectiveness of investments in carbon sequestration from forests.

IV. FOCUSING MRV AND INCENTIVES ON CLIMATE-SMART FORESTRY PRACTICES

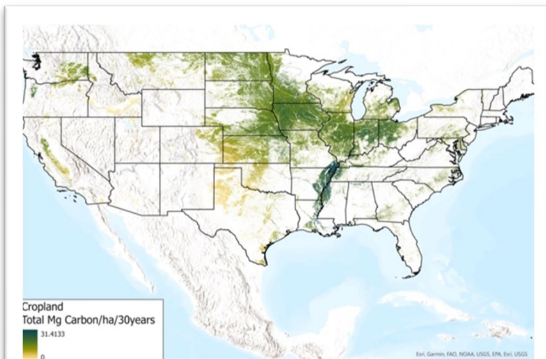
This section identifies and explores six illustrative areas in which the deployment of “climate-smart” forestry practices can increase carbon removals and/or avoid carbon emissions while generating other nature-based benefits. As referenced above and discussed in more detail below, there is active interest in expanding investments in all six of these areas — (A) agroforestry, (B) reforestation, (C) urban forestry, (D) improved forestry management, (E) long-lived wood products, and (F) bioenergy with carbon capture and storage (BECCS). This makes now the ideal time to simultaneously invest in new measurement, monitoring, reporting and verification tools that can quantify these climate wins. These investments will provide a solid foundation to incentivize the broad adoption of these climate-smart forestry practices.

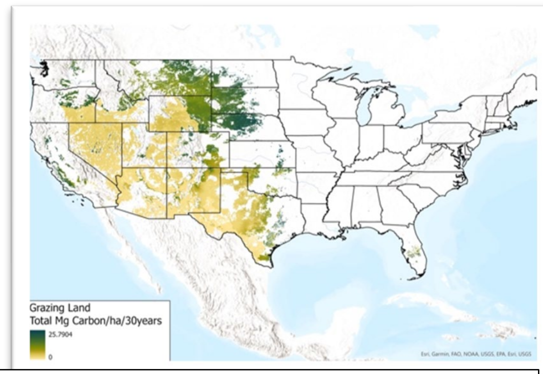
A. Agroforestry – "Bringing the Forest to the Farm"

Recent scientific research confirms that there is "large climate mitigation potential from adding trees to agricultural lands."[47] Agricultural lands already store nearly 7 Gt of carbon globally through aboveground woody biomass. The introduction of trees to agricultural lands generally could increase carbon storage in agricultural lands by an estimated 0.94-9.4 Gt C under different adoption scenarios, representing up to 7.6% of the total climate change mitigation that is needed by 2030 to keep warming to below 2°C.[48]

Yet despite its enormous potential to increase carbon removals, only about 1.5% of U.S. agriculture is classified as agroforestry according to a recent analysis[49] by the USDA's National Agroforestry Center (NAC).[50]

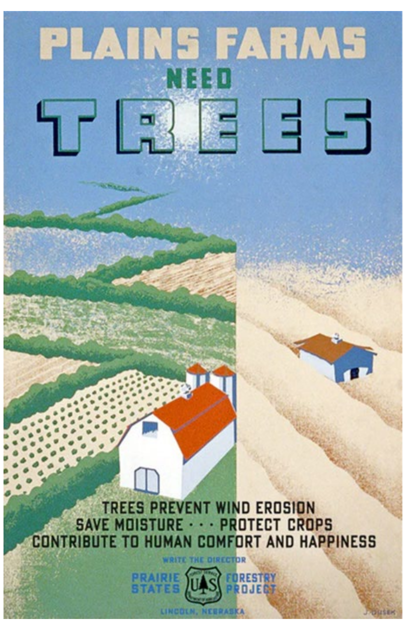
Potential for additional trees in crop and grazing lands in the US (lands with existing forest cover of <25%):





Maps from Sprenkle-Hyppolite, S., B. Griscom, V. Griffey, E. Munshi, M. Chapman, *Global CDR Potential of Trees in Agriculture* (forthcoming).

In addition to carbon sequestration, agroforestry also provides a wide range of additional ecosystem services, including improving climate resilience through shade from extreme heat, income enhancement, hydrologic benefits to water retention and water quality, increasing pollination services, and improved soil health.[51] In fact, one of the most successful projects in USDA history was the "Great Midwestern Shelterbelt" restoration project, which introduced windbreaks in the 1930s to protect farms against wind during the dust bowl. Recent empirical research from Columbia University has shown that this historic large-scale afforestation project of windbreaks and tree lines on croplands dramatically improved not just carbon sequestration but also yields, soil moisture, and even precipitation.[52]



The success of the Great Midwestern Shelterbelt is a testament to the power of coordinated federal efforts to respond to existential environmental threats. It also showcases the potential of agroforestry as a valuable tool for addressing these challenges while supporting producers and agricultural communities.

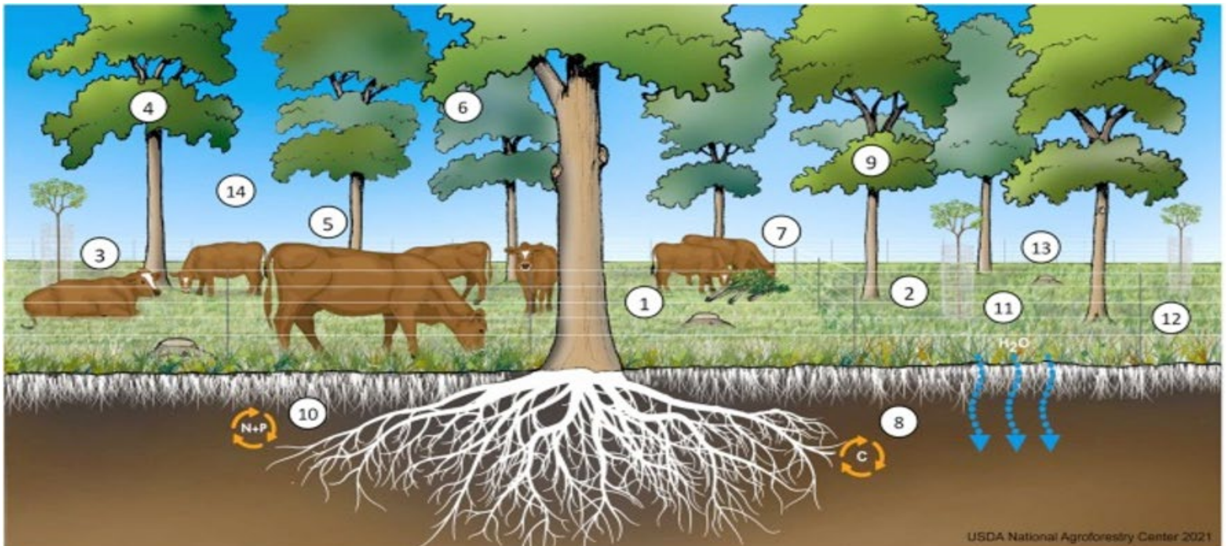
Primary Agroforestry Practices.

Agroforestry can encompass a variety of practices that vary by climate, soil type, hydrology, and other biotic or abiotic factors.

A core agroforestry practice is **silvopasture**—the intentional addition of trees to pastureland. Silvopasture is particularly well-positioned for expansion in the U.S. given the extensive pastureland in the U.S. and the inexpensive and relatively straight-forward opportunity to measure and confirm practice adoption through both localized and remote sensing capabilities.

Similarly, installing **windbreaks** – rows of trees around edges of fields, primarily to protect from wind damage and erosion – is the tried-and-true practice that already has had a positive impact on the American Midwest through the Shelterbelt project nearly a century ago.

Planting trees in accordance with these two practices have significant potential to capture additional carbon and generate enhanced revenue streams for farmers and ranchers. A recent publication concluded, for example, that "restoring forests to pasture lands represents the single largest opportunity to mitigate climate change" as "the opportunity class contains over half of the area of opportunity (56%) and two-thirds (66%) of the mitigation potential… and some of the lowest cost opportunities" for carbon sequestration.[53] As additional evidence of silvopasture's attractive environmental and economic benefits, so-called "fodder trees" in silvopasture lands can "reduce the need for feed through forage, increase resilience to extreme heat, create income diversification, and provide a range of ecosystem services pertaining to soil carbon, nutrient cycling, water infiltration, biodiversity, and aesthetic benefits," as illustrated in the graphic below (from endnote n.57).



Key	Component	Summarized primary effects	Key references
1	Forage	Microclimate modification can maintain or enhance forage yield and quality compared to open pasture depending on species and management.	Buergler et al. (2006), Ford et al. (2019b), Fannon et al. (2019), Orefice et al. (2019), Pang et al. (2019a, 2019b)
2	Forage	Potential for extending forage growing season and yields due to microclimatic modification in droughty summer months and reducing radiation frosts in early and late season.	Frost and McDougald (1989), Feldhake (2002), Kallenbach et al. (2006), Coble et al. (2020)
3	Livestock	Shade reduces solar radiation and heat stress which can enhance animal productivity.	Karki and Goodman (2010), Schütz et al. (2014), Van laer et al. (2014), Pent et al. (2020b, 2021)
4	Livestock	Shelter from trees can offer thermal protection for livestock during winter by reducing wind and precipitation reaching sheltering animals.	Van laer et al. (2014, 2015), He et al. (2017)
5	Livestock	Livestock weight gain in silvopastures can be comparable to that of livestock grazed in open pastures depending on species and management.	Kallenbach et al. (2006), Ford et al. (2019b), Pent et al. (2020a)
6	Tree	Trees in silvopasture can produce products to increase enterprise diversification. Tree growth can benefit from nutrient input but may be negatively impacted by livestock if not adequately managed.	Ares et al. (2006), Broughton et al. (2012), Bruck et al. (2019), Pent 2020
7	Tree	Leaf fodder and mast (e.g., acorns, honey locust pods, apples) can augment livestock diets and offer nutritional value depending on species.	Moreno et al. (2018), Vandermeulen et al. (2018), Pent and Fike (2019), Hassan et al. (2020), Seidavi et al. (2020)
8	Ecosystem service	Soil carbon storage is increased at various soil horizons and depths when converting from open pasture to silvopasture but may decrease when converting from forest.	Haile et al. (2008, 2010), Baah-Acheamfour et al. (2014, 2015), De Stefano and Jacobson (2018)
9	Ecosystem service	Soil and biomass carbon sequestration is generally higher in silvopasture than open pasture but may be lower than forests.	De Stefano and Jacobson (2018), Lal et al. (2018)
10	Ecosystem service	Silvopasture can enhance nutrient recycling and reduce phosphorus loss and nitrate leaching when compared to open pasture.	Michel et al. (2007), Bambo et al. (2009), Boyer and Neel (2010), Nyakatawa et al. (2012)

In addition to carbon, and as noted in the graphic, agroforestry systems also have been shown "to mitigate nitrous and carbon dioxide emissions from the soils and increase the methane sink strength compared to annual cropping systems."[54] The same study continued, "Data from several countries strongly suggest that agroforestry systems can partially offset methane emissions, while conventional high-input systems exacerbate methane emissions."[55] The fact that agroforestry practices can reduce nitrous oxide and methane emissions—while also providing tree-based carbon sequestration — is a major benefit, given that the agricultural sector is a major source of these powerful greenhouse gases.[56]

Climate Adaptation Co-Benefits.

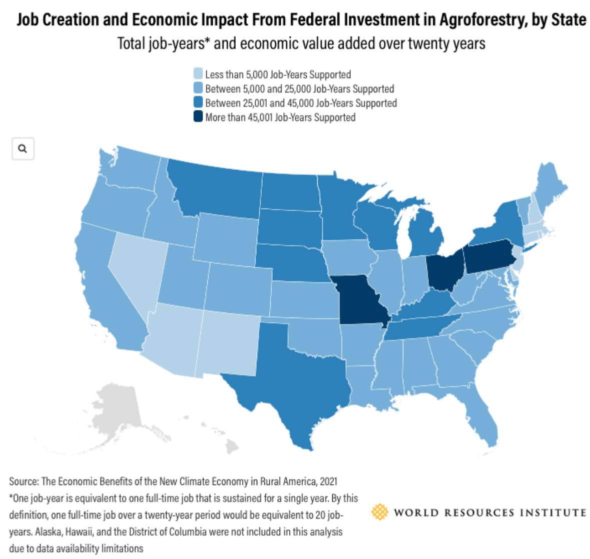
Expanded adoption of agroforestry practices will generate multiple climate adaptation benefits in addition to carbon sequestration, including yield, water, soil, and heat mitigation.[57] As summarized in a recent scientific publication:

> "Agroforestry can contribute to climate change adaptation in four ways: (1) reversal of negative trends in diverse tree cover as generic portfolio risk management strategy; (2) targeted, strategic, shift in resource capture (e.g. light, water) to adjust to changing conditions (e.g. lower or more variable rainfall, higher temperatures); (3) vegetation-based influences on rainfall patterns; and (4) adaptive, tactical, management of tree-crop interactions based on weather forecasts for the (next) growing season. Evidence for the generic risk reduction by increase of buffer functions and diversity is strong; examples of specific adaptations to confirmed trends in local climate are still sparse, but are starting to emerge, especially with respect to hydroclimatic change."[58]

The increasing climate impacts of extreme events such as heatwaves, stormwater flooding, and drought indicate that the economic value of these climate buffering co-benefits will only grow in the future. In fact, leading scientists have argued that "carbon sequestration can, and perhaps should, be viewed as one co-benefit of reforestation strategies designed to protect and intensify the hydrologic cycle and associated cooling."[59]

Agroforestry Commodities and Jobs in Rural America.

Agroforestry presents the USDA with a rich opportunity to stimulate job creation and economic benefits to farmers and rural communities. Since establishing and maintaining agroforestry practices requires specialized expertise and can be labor intensive, the World Resources Institute estimated that an annual federal investment of $1.8 billion in agroforestry could support 49,500 jobs annually, or 27.4 jobs per million dollars invested.[60]



The market and revenue opportunities to farmers from Agroforestry products could be transformative. From 2003 to 2013, for instance, permanent crop income in the U.S. averaged an annualized return of 12.2%, compared to just 4.5% for annual crops.[61] Shrub crops like elderberries and black currants, high margin nuts like hazelnuts and chestnuts, and "shade grown" beef and chicken are all high value climate smart commodities that require market development resources to reach their full potential. *See* Appendix D.

To help catalyze the development of Agroforestry commodities, the USDA awarded $60 million to The Nature Conservancy (TNC) and multiple partners under the Partnerships for Climate-Smart Commodities initiative to fund a 5-year project to advance agroforestry in 29 states.[62] Through a regionalized framework, agroforestry practitioners, researchers, and corporate partners will model how agroforestry can be scaled in the U.S. and demonstrate two major propositions: First, that markets can be develop for premium-priced agroforestry commodities and, second, that agroforestry practices can sequester significant quantities of carbon. Each is discussed below, in turn.

Developing markets for premium-priced agroforestry commodities. Each climate smart product has measurable economic potential but is in effect a start-up business. As Fred Iutzi from the Savanna Institute who leads this effort explained: "Nonprofits, like us, can accelerate the start-up process. We provide development assistance and value chain connections to push a market that doesn't pencil out economically to the point where it does. Since this is an emerging sector, and it's not knit together, we incubate market connections and help companies move in and set up shop faster."[63] Since farmers will not see profits from these products for several years, $40M of the $60M will be used for direct incentives. But more investment is needed to scale, including creative equity financing from the private sector and additional incentives and technical assistance from the USDA. Ongoing partnerships with these regional partners will be a key to success.

Sequestrating Significant Quantities of Carbon. The TNC-led project seeks to transform 30,000 acres into agroforestry systems over the next five years. Within 10 years, the project is hoping to facilitate the adoption of climate-smart agroforestry practices such as alley cropping, silvopasture, and windbreaks on 10% of U.S. farmland. Because agroforestry sequesters 2 to 5 tons of carbon per acre per year, the level of adoption expected from this single project potentially could generate carbon sequestration equivalent to 1 to 2.5% of 2020 U.S. emissions from all sources by 2028. With additional investment in incentives and training from the USDA, over 20 years high-density agroforestry could be implemented on 80 million acres of farmland, potentially mitigating 3 to 6% of the country's 2020 emissions.[64]

> *"After 30-plus years of work on agroforestry in the United States, the sector's moment has arrived. It's a blessing and a curse because on the one hand, our sector has never seen this level of commitment to agroforestry, on the other, we are still woefully unprepared, without enough service providers appropriately equipped to train farmers in the modern forms of agroforestry." Megan Giroux, Interlace Commons*

Measuring and Monitoring Agroforestry's Carbon, Climate Adaptation and other Co-Benefits.

While the carbon sequestration, climate adaptation and other benefits of agroforestry are widely known, there has not been significant effort to quantify these benefits at the aggregate-, regional- or project-based levels. Despite significant carbon sequestration potential, for example, data on agroforestry in the United States remains scarce, as illustrated by the fact that the USDA Agricultural Census only asks farmers a single yes or no question about whether they practice agroforestry. The FIA sampling methodology also short-changes agroforestry, which often contains clustered trees, scattered trees, or tree lines that get missed by the traditional FIA plot-based sampling methodology.

We recommend that the National Agroforesty Center be tasked with undertaking this critically important work including, in particular, the centrally-important exercise of developing measurement and monitoring approaches and related protocols. The USDA should substantially increase the budget and capability of the National Agroforestry Center (NAC) and charge it with:

- **Obtaining census data regarding the nature and scope of agroforestry operations in place today in the U.S.; and**
- **Addressing the significant gaps in MRV data and protocols for agroforestry by systematically identifying agroforestry practices by region and, for each, obtaining and analyzing field-based and remote sensing data to evaluate carbon sequestration benefits (using tools developed in other forestry and agricultural contexts) and developing qualitative and quantitative approaches for measuring agroforestry co-benefits.**

A Key Role for NRCS: Technical Support and Outreach to Farmers and Ranchers.

A major reason why the U.S. has not taken more advantage of agroforestry practices is agroforestry's status as an "orphan" that sits in-between and outside the embrace of agriculture and forestry — the USDA's two largest bureaucratic programs. Despite its central role in the history of NRCS and the USDA, implementation of agroforestry is still largely limited to the National Agroforestry Center, which has operated primarily as a research-oriented unit of the Forest Service.

Agroforestry development will continue to languish without the type of on-going technical support and outreach that is NRCS's bread and butter. Currently, the NRCS has limited capabilities in agroforestry. **We recommend that NRCS:**

- **Set aside $1 billion of the $19.5 billion in the Inflation Reduction Act's conservation funding to incentivize the adoption of high-value agroforestry practices, targeting silvopasture and windbreaks.** The incentives should be tailored for the early years of adoption when the economic returns will not yet be evident to farmers.

- **Invest in capacity building to train extension agents.** To support the expansion of agroforestry, the NRCS needs to increase its internal agroforestry capacity among extension agents. Funds should be allocated to train and hire new agroforesters on a regional basis. The requirements for these positions should reflect the interdisciplinary reality of agroforestry, encompassing not just forestry, but also agricultural sciences, soil sciences, ecology, and economics.

- **Set a DOE-type "EarthShot" goal[65] for a major agroforestry initiative.** The USDA's agroforestry EarthShot should:

    i. Create a Joint Chiefs' Agroforestry Initiative, modeled on the Joint Chiefs' Landscape Restoration Partnership, to align the NRCS and USFS/NAC in the pursuit of jointly established agroforestry acreage goals, timelines to develop MRV and protocols, and technical support and outreach.
    ii. Convene 6-month reviews with NRCS, NAC, and FS to iron out inefficiencies and inconsistencies, and provide a platform to connect with leading international organizations like CIFOR/ICRAF to access additional expertise.

- **Leverage partnerships to scale up agroforestry.** Time is of the essence. While building out its own capacity, the USDA should empower known partners to help execute regional agroforestry practices. Private sector companies, NGOs, extension agents, and other relevant agencies should all be engaged to provide resources to work with farmers and build momentum from demonstration sites. Newly trained cohorts of technical assistance providers should collect data on the extent of existing practices, interest, and regional potential for implementation. Alongside collection and distribution of this data, cutting red tape at the state level that prevents these organizations from assisting farmers, or prevents farmers from accessing incentives, will accelerate progress.

B. Reforestation — A Necessity and an Opportunity

Reforestation refers to the establishment of new trees in areas that have historically been forests but have been degraded due to wildfire, land conversion, disease, or other natural and human disturbances. Reforestation can re-establish valuable carbon sinks and produce numerous co-benefits such as clean water, reduced flooding, improved soil health, expanded wildlife habitat, and enhanced forest resilience.[66] In addition to the environmental benefits, reforestation can provide economic benefits by providing jobs, particularly to tribal and rural communities. During the New Deal era, reforestation efforts facilitated through the Civilian Conservation Corps provided a powerful lever for economic recovery, and they could generate similar economic benefits again today.

Reforestation can occur through natural regeneration or through the purposeful planting of new trees. While natural regeneration is sometimes preferred due to lower costs, stressors such as rising temperatures, increased and prolonged drought, larger and more severe wildfires, and intensified pest activity have slowed the rate and quality of natural regeneration. Experts have concluded that natural regeneration will not meet today's reforestation needs. Additionally, natural regeneration in severely burned areas can trigger the growth of non-forest vegetation such as grass and shrub systems that have lower carbon sequestration rates and fewer co-benefits.[67]

Given natural regeneration's limitations, tree planting with the right mix of species at the right times and places is more critical than ever. Planting can either be done as a reforestation exercise—that is, establishing trees on existing forested land—or as afforestation—establishing trees on non-forested land or on former forested land where trees have been absent for longer than 50 years.[68] In this report, references to reforestation encompass both reforestation and afforestation activities.

The "Reforestation Hub"—a joint project of The Nature Conservancy and American Forests—estimates that there are nearly 150 million acres of reforestation potential in the U.S., split between private lands (approximately 130 million acres) and public lands (approximately 20 million acres).[69]

Based on its FIA database, the Forest Service suggests that the reforestation opportunity on private lands is closer to 50 million acres. On public lands, a joint Interior and Agriculture Department report estimates that approximately 23 million acres of public lands are available for reforestation — similar to the Reforestation Hub's estimate.[70]

Regardless of the data and methodologies that are used to estimate the reforestation opportunity in the U.S., it undoubtedly very significant.

Ownership

Ownership	CO_2 (t/yr)	Acres
Total opportunity	534.75 M	148.17 M
Private	492.62 M	130.86 M
Federal	26.06 M	12.34 M
US Forest Service	17.88 M	6.92 M
Bureau of Land Mgmt	5.8 M	4.39 M
State	11.36 M	3.69 M
Other	4.72 M	1.3 M

This reforestation ownership chart can be found at www.reforestationhub.org

New Funding.

In 1980, Congress created the Reforestation Trust Fund to plant trees on national forests in the aftermath of natural disturbances such as wildfires. The fund was replenished by tariffs collected on wood products and was capped at $30 million annually.

As noted above, the Repairing Existing Public Land by Adding Necessary Trees (REPLANT) Act was enacted in 2021 as part of the Bipartisan Infrastructure Law. The REPLANT Act removed the $30 million funding cap from the 1980 bill and directed all wood product tariffs to refill the Reforestation Trust Fund—which quadrupled the amount of available funding to $123 million per year on average. The Forest Service has projected that additional funding from the REPLANT Act will enable it to plant 1.2 billion trees and create nearly 49,000 jobs annually over the next ten years.

The REPLANT Act also directed the Forest Service to develop a 10-year plan and cost estimate to address the backlog of replanting needs on national forest land. In July 2022, the Forest Service released its Reforestation Strategy, which outlines five goals and supporting objectives necessary for successful reforestation on national forests. It emphasizes the importance of collaborating with partners and prioritizing biodiversity when pursuing reforestation efforts.[71] The White House issued Executive Order 14072 in April 2022, which called for the Secretaries of the Interior and Agriculture to develop reforestation targets and a climate-informed reforestation plan. As noted above, the Departments of Agriculture and Interior released a joint reforestation report in April 2023.[72]

In addition to federal funding that is underwriting expanded reforestation activities on Forest Service, Bureau of Land Management and other federal lands, many states and private foresters are actively engaged in reforestation efforts. This activity is proceeding against the backdrop of broad-based national and global momentum toward large-scale reforestation, as illustrated by the World Economic Forum's One Trillion Trees initiative and its U.S. chapter's recruitment of major reforestation pledges from companies, NGOs, and governments.[73]

Measuring the Potential Carbon Benefits from Reforestation.

While some experts have speculated how much carbon potentially could be captured from an aggressive reforestation effort,[74] new measurement and monitoring tools make it possible to greatly improve estimates of much carbon is captured and sequestered through reforestation efforts.

Reforestation and afforestation gains at medium spatial scales (10-30 meters) are detectable in land cover change maps generated by the government and academic communities. Also, the recent availability of multimodal high-resolution multispectral, radar, and LiDAR sources can contribute to higher quality mapping procedures. Many satellite and remote sensing based land cover mapping methods are of sufficient spatial resolution to perform this task, with the proviso that a current day forest cover must be referenced against a past baseline to produce an accurate quantification.

To improve accuracy, land cover data should be augmented with information about the density of trees, height, height, or species distribution on reforested lands using new methods that involve the direct prediction of aboveground biomass, root carbon, and total sequestration using machine learning algorithms. The non-profit CTrees.org introduced a new global map product last year at the Egypt COP that includes these more granular estimates that can be developed for reforested acreage, as tested against baseline conditions.[75]

We recommend that the MRV tools described above in Section II — including remote sensing and machine learning — be applied to identify baseline conditions and to track and project anticipated reforestation carbon sequestration increases at the project level.

Implementation Challenges.

Despite the growth of reforestation and afforestation efforts in recent years, many tree-planting projects have resulted in abject failure. Some experienced widespread mortality within the first three years.[76] To be successful at scale, orchestrated attention must be directed at every stage of the "reforestation pipeline." The following graphic illustrates the place-, supply-, and people-based project management challenges associated with reforestation activities:

Reforestation Pipeline

<table>
<tr><th>Stage</th><td>Land Assessment</td><td>Project Planning</td><td>Cone Collection</td><td>Seed Storage</td><td>Seed Processing</td><td>Seedling Growing</td><td>Site Preparation</td><td>Tree Planting</td><td>Monitoring</td><td>Tending</td></tr>
<tr><th>Location</th><td>Project Site</td><td>Office</td><td>Nearby Project Site</td><td colspan="3">Nursery</td><td colspan="4">Project Site</td></tr>
</table>

The Departments of Agriculture and Interior and key partners have prepared excellent planning documents in anticipation of the need to scale up reforestation activities.[77] The challenge now is in execution.

Workforce Challenges. Sophisticated expertise is needed to inform the appropriate species of trees that should be planted and the optimal planting regime that will advance multiple goals of promoting biodiversity,[78] wildlife, carbon sequestration, and the like, and taking into account changing climactic conditions that may impact trees over their projected lifespans. The workforce challenges are daunting. A robust reforestation scheme requires experts at every key reforestation stage, including seed collection, nursery management, and ecological monitoring. As the Forest Service stated in its Reforestation Strategy, there is a large gap between the current number of reforestation experts at the USDA and the number needed to execute a thorough reforestation effort.

Accordingly, we recommend:

- **The Forest Service and other federal land management agencies must accelerate attention on reforestation workforce issues by collaborating with other agencies and non-governmental organizations and investing in employees, contractors, and partners to scale reforestation efforts.**

Seed and Seedlings Availability. Additional challenges for reforestation projects include the availability of genetically appropriate seeds and seedlings. To illustrate, cone collection is critical because without sufficient genetically-diverse, climate-adapted seed, it will be difficult or even impossible to rebuild resilient forests. The Department of the Interior and the USDA have made recommendations to ramp up cone collection through expanded orchards and workforce development, but increased collaboration and partnerships with non-Federal organizations are needed for these recommendations to succeed.[79]

Particular attention is needed on seed collection from public lands in the west to obtain genetically diverse seed supplies, including access for seed collection on Forest Service lands. Enabling cone collection on National Forests at scale is essential for meeting reforestation needs and can be done in a way that enables rural development, facilitates public-private partnership, and provides fair public compensation for the collections, including serving the Forest Service's own needs.

Accordingly, we recommend:

- **The federal government should establish a national tree seed collection permit or MOU system for non-Federal organizations on Federal lands in line with recommendation 2.2 and 2.5 from the joint report issued by the Departments of Agriculture and Interior.**[80]

C. Urban Forestry — Carbon, and More

Surprisingly, more than 140 million acres of forests are located in urban areas–amounting to approximately one-fifth of the forest cover in the entire U.S.[81] As a corollary, experts also attribute nearly one-fifth of the carbon that U.S. forests are removing from the atmosphere every year estimate to urban forests.[82]

There is an important opportunity to protect and expand urban forests in the U.S. and, as a result, increase the carbon sequestration and other benefits that urban forests produce.[83] The Joint Reforestation Report produced by the Interior and Agriculture Departments estimates nearly 8 million more acres of urban land are available for tree planting.[84]

Expanding urban forestry can play a vital role in combating climate change through direct carbon sequestration and mitigating the most consequential effects of climate change, such as rising temperatures. In recent years, trees in urban areas are belatedly being recognized as a key part of the climate solution. In addition to removing carbon from the atmosphere, urban trees can provide multiple valuable benefits to city-dwellers, including reduced heat, flood mitigation, filtering air pollution, and promoting equity.

New Funding

Historically, federal funding through the USDA's Urban and Community Forestry program has been limited, averaging only around $30 million a year–not even $1 million per state.[85] As a result, states and cities have largely needed to rely on their own budgets to maintain and, where possible, expand their urban forestry programs.

The Inflation Reduction Act dramatically changed the pattern, however, by appropriating $1.5 billion for the USDA's Urban and Community Forestry Program. Plus, importantly, it directed that the funds be preferentially invested in historically overlooked and disadvantaged urban areas.[86]

With these substantial new resources, the federal government has an extraordinary opportunity to help local urban communities leverage their limited urban forestry budgets and expand their urban forestry programs—reaping multiple benefits, as described below. American Forests estimates that the $1.5 billion in the Inflation Reduction Act, along with matching contributions from funding recipients, can facilitate the planting and preservation of 40 to 50 million urban trees.[87]

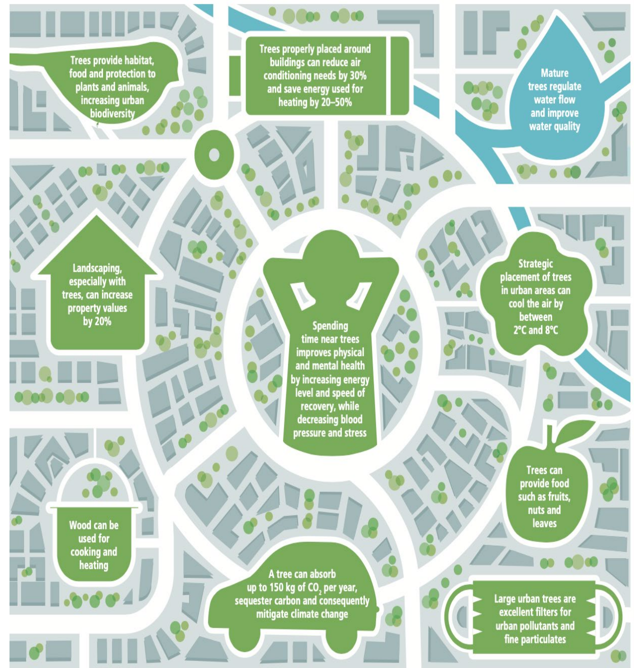
American Forests estimates that this new funding may yield around 25 million tons of additional carbon capture and storage in urban forests by 2030 — on top of the estimated 708 million tons of carbon stored in urban forests and the 28.2 million tons of additional tons that are captured and sequestered in urban trees each year.[88]

Strategies for Measuring and Monitoring Carbon and Other Benefits from Urban Forests.

As emphasized throughout this report, it is important to deploy new measurement and monitoring tools that will generate solid, activity-level estimates of carbon removal benefits from new urban forestry investments. As with other climate-smart forestry practices, however, carbon benefits are only part of the story.

Carbon Benefits. Existing strategies for measuring carbon sequestration in urban forests primarily rely on mapping the tree cover within a region and then using estimates of carbon benefits per unit area to calculate individual tree or broad-scale carbon storage.[89] The Center of Urban Forest Research's Tree Carbon Calculator uses this method. The resulting carbon sequestration estimates lack precision because per unit area estimations are based on samplings from differently-situated cities within a region.

More recent estimation applications—such as ecoSmart Landscapes in California and the Forest Service's i-Tree application[90]—improve on previous methods, but they still use sampling-based allometries to estimate tree carbon which may result in mismatches in data granularity when applied to different scales—particularly when broad-spatial averages are used to represent fine-spatial scales including, for example, carbon benefits for small tracts or defined project areas.[91] Notably, the urban FIA program uses the i-Tree tool to track trees,[92] so its national scale analysis of urban trees reflects the i-Tree tool's limitations.[93]



This graphic illustrates the additional benefits urban forests provide beyond carbon sequestration.
Source: World Forum on Urban Forests; link: https://www.worldforumonurbanforests.org/media-2/infographics.html

There are many other urban tree data sets that collect detailed data on numbers, types and locations of city trees. Many cities such as New York City,[94] San Francisco,[95] and Chicago[96] undertake comprehensive tree censuses that map trees in their respective cities, including tree species and health. 25 cities currently participate in the FIA's urban tree program, which hopes to involve over 100 cities as part of the national urban forest inventory.[97] The FIA urban tree program collects highly detailed information about trees, including species, height, crown condition, damage, and ground cover. These reference data sets could enable the development of sophisticated machine learning (ML) models that would detect and map urban trees and, when coupled with high-resolution satellite imagery, would generate more precise estimates of carbon and other benefits that the trees are providing. New datasets, such as Google's Auto Arborist benchmark, also leverage ML methods to gather better information about urban trees.[98] Together, applying these new tools to strong urban data sets could potentially enable continent-wide mapping down to individual tree crowns and the carbon sequestered by small stands or even individual trees.[99]

Based on this background, we recommend:

- **The USDA and Forest Service should partner with the U.S. Digital Service and other data management experts to develop carbon measurement tools that take advantage of remote sensing capabilities and machine learning to generate carbon sequestration baselines and updates for urban forests**. (See Section II, above.)

- **The USDA and Forest Service should partner with states, cities, outside NGOs and forestry experts to develop a national urban tree spatial dataset. Creating a comprehensive dataset would facilitate the assessment of national goals, enable monitoring of canopy cover changes, track species composition, and measure shifts in carbon storage.**

Co-Benefits. In addition to carbon sequestration, urban forestry can generate numerous, well documented co-benefits.[100] As illustrated in the graphic above, examples include reducing heat, improving air quality, conserving energy use, mitigating flooding and storm damage, reducing noise, increasing health, ecological stability, and improving neighborhoods. Several of these co-benefits improve communities' resilience in the face of climate impacts such as extreme heat, flooding and storm damage.

Researchers have made some important advances in seeking to qualitatively and/or quantitatively measure and monitor co-benefits. Because some of these learnings may be applicable to (or potentially inspire) other climate-smart forestry co-benefit quantification efforts, they are summarized briefly below.

Equity. An increase in equity is one of the most important co-benefits that can accompany urban forestry initiatives. Due to historical inequities, many U.S. cities have generous tree cover in more affluent areas, while disadvantaged areas have tree deficits that make them more unhealthy and less desirable places to live.

American Forests has developed a measurement tool that identifies cities' "Tree Equity" scores based on existing tree canopy, human population density, income, employment, surface temperature, race, age and health.[101] Historically redlined urban neighborhoods, for example, tend to be 13°F hotter than neighborhoods that were not redlined due to the lack of tree cover.[102]

The availability of the Tree Equity tool enabled the District of Columbia government to purposefully introduce trees in disadvantaged areas, transforming the city from having one of the lowest tree equity scores to attaining one of the highest (*see* Appendix D). Having this (and other) equity measurement tools will enable the Administration to confirm that at least 40 percent of the IRA's $1.5 billion in urban forestry spending will flow to disadvantaged communities, as called for by the Justice40 initiative.[103]

Extreme Heat. Heat is the nation's most deadly climate-related extreme weather-related event.[104] Increased heat is exacerbated in urban areas due to the "urban heat island effect"—the condition through which asphalt, buildings, and other urban surfaces absorb heat and act as elevated heat sources. A lack of tree cover to provide cooling shade and block the sun from these surfaces further exacerbates heat absorption. Consequently, after climate change, urban expansion is the leading cause of increasing temperatures in cities.[105]

Urban heat and its deadly effects can be mitigated by expanding urban tree cover. Indeed, studies have shown increasing urban tree cover can reduce heat deaths in cities by nearly one third.[106] Some leading cities already are demonstrating these positive impacts. *See* Appendix F.

To measure the benefits of heat reduction from urban trees, it is essential to quantify the extent to which tree canopy cover can lower average temperatures. While the precise reduction varies on factors such as tree species and tree arrangement, heat reduction is measurable. For example, previous research found a 10-25% percent increase in canopy cover reduced air temperature by 2.0°C.[107]

Air Quality. Trees also can remove pollutants directly from the air. One study found that planting 500,000 trees in Tucson, Arizona generated $1.5 million worth of benefits per year from the reduction of pollutants in the air.[108]

The quantification of air quality benefits provided by urban forests involves assessing the pollution removal capacity of different tree species. Previous research has used estimations based on the amount of pollution removed by each tree species on a per-county basis and the corresponding pollutant emissions from the National Emissions Inventory.[109] To determine the improvements in ambient air quality, estimates of annual pollutant removal by species by county can be converted into average annual improvements in air quality. An integrated assessment model (e.g., AP3 model) is then utilized to link emissions of common air pollutants by county in the U.S. to ambient concentrations of $PM_{2.5}$ and ozone. By employing this model, researchers can calculate county-level exposures, mortality risk, and monetary damages associated with baseline pollutant levels. The average annual damage caused by a pollutant in a county is calculated by dividing the monetary damage predicted by the AP3 model for that pollutant in a given year by the ambient concentration of the pollutant in the county during the same year.[110]

Energy Conservation. Urban trees, when placed in an appropriate location, can reduce the summer cooling costs of urban buildings.[111] This is a quantifiable benefit. States like California have tools that enable developers to calculate estimated energy savings based on tree types and their location relative to impacted buildings.[112] In addition to the financial benefits, reduced energy use also reduces carbon emissions, creating an indirect carbon benefit from urban forestry.

Energy savings resulting from the presence of urban forests are calculated by employing numerical models that consider various factors.[113] For example, researchers compared otherwise-identical shaded and unshaded buildings to determine energy usage using observed residential energy data. Several parameters influence the overall amount of energy savings achieved, including tree crown shape, building proximity, azimuth, local climate, and season.[114]

Similarly, the presence of urban forests contributes to the reduction of carbon emissions by minimizing the demand for energy from power plants and space-heating equipment.[115] The quantification of avoided carbon emissions involves considering factors such as energy savings, fuel mixes, emission factors, and localized retail residential and natural gas prices. Calculations of energy savings are expressed as real-dollar amounts, determined by applying the overall reductions in oil and gas usage or electricity usage to the regional cost of oil and gas or electricity for residential customers. Energy savings tend to vary depending on the climate of the region, where colder regions often experience larger savings in heating, while warmer regions tend to see greater savings in cooling.[116]

Urban Hydrology. Urban forests can also help cities adapt to the increasing threats of flooding and stormwater posed by climate change. While savings per tree will vary by species and location, improving canopy cover in cities can reduce runoff. For example, the urban tree planting program in Boise has already had significant positive impacts, capturing over 100 million gallons of stormwater.[117] *See* Appendix D. Additionally, it is important to consider that certain tree species may incur higher water costs compared to the energy savings they offer through shading buildings, highlighting the importance the urban foresters engage in careful planning and management.[118]

Urban forests play a crucial role in intercepting rainfall, helping to control stormwater runoff and reduce associated costs. A numerical interception model has been employed to estimate the amount of rainfall intercepted by trees, taking into account canopy architectural features (e.g., species-specific leaf surface areas), which control interception capabilities.[119] The rainfall interception benefit is monetarily quantified by estimating the costs of controlling stormwater runoff, considering factors such as water quality and flood control costs per unit volume of runoff controlled.[120] This cost is then multiplied by the annual amount of rainfall intercepted by trees. (For additional information on urban forestry co-benefits, *see* Appendix G.)

Based on these encouraging developments, we recommend:

- **The USDA and Forest Service, working with states, cities, NGOs and other urban forestry experts should build into their grants data collection requirements that will enable the USDA to build and share a larger quantification data set that measures and monitors the carbon and other benefits associated with urban forestry investments including, but not limited to, equity, extreme heat, air quality, energy conservation, and urban hydrology.**

Key Implementation Challenges.

Effective urban forestry management strategies are essential for creating sustainable and resilient urban ecosystems. By investing in research for appropriate tree species, implementing inclusive planting strategies, dedicating funds for ongoing maintenance, and promoting community engagement, cities can maximize the benefits of urban forests. Additionally, ensuring tree equity and mitigating environmental gentrification are vital considerations in creating equitable and thriving urban environments. By implementing these recommendations and monitoring pertinent metrics in local-governments, cities can enhance their urban forestry programs, improve the quality of life for their residents, and contribute to national global efforts in mitigating climate change.

To optimize the effectiveness of urban forestry, it is critical to consider the significance of location and management. Careful consideration must be given to tree selection and placement, as using a poorly adapted tree species or improper placement can diminish or even extinguish potential co-benefits. For example, trees planted on the wrong side of buildings can increase energy costs because they may cool buildings in the winter.[121] Moreover, certain tree species have higher water requirements that may not be appropriate in water-short cities. Accordingly, maximizing ecosystem service delivery requires investment in determining which tree species compositions will thrive in their respective cities and climates. Thoughtful construction of tree mixes is critical to ensuring resilient trees.[122]

More generally, the success of urban forestry management efforts should be tested against five key metrics: (1) tracking changes in canopy cover; (2) forest health, measured by species diversity, suitability to local climate conditions, and overall well-being; (3) tree protection, measured by success in conserving existing trees; (4) community engagement in tree planting and management activities; and (5) tree equity scoring to ensure that plantings and subsequent management occur in historically underserved areas for equitable delivery of ecosystem services.[123]

Taking these points into account, we recommend:

- **The USDA and Forest Service, working with states, cities, NGOs and other urban forestry experts should ensure that its grantees use a co-production approach to decision-making which involves local communities, neighborhood associations, and NGOs.** Thoughtful community engagement can help to bridge gaps between risk assessments and community preferences.

- **Cities should take advantage of their locally adapted and native species as well as trees that are tolerant to environmental stress (e.g., drought).** Paying particular attention to ensuring high biodiversity within tree mixes will maximize carbon sequestration potential and increase ecosystem resilience.[124]

D. Improved Forest Management Practices

Improved Forest Management, or IFM, refers to "activities which result in increased carbon stocks within forests and/or reduce GHG emissions from forestry activities when compared to business as usual forestry practices."[125] When successful, IFM has been shown to accelerate carbon stocking, increase resilience, and enable broader ecosystem and societal co-benefits.[126] A 2018 analysis found that "natural forest management" has the potential to mitigate 267 Tg CO2e year, representing more than 20% of the total mitigation potential for all natural climate solutions in the U.S.[127] Other studies have shown similarly large potential simply from changes to management practices.[128]

Along with its great potential there are numerous important challenges to measuring and validating climate benefits from IFM practices:

The relationship between direct removals and avoided emissions. IFM has the potential for benefits on two broad dimensions: direct removals and avoided emissions. On the one hand, IFM practices that directly increase the rate of sequestration of carbon in a forest's carbon pools (e.g., extended harvest rotations or crop tree thinning treatments) can contribute to direct removal of carbon from the atmosphere. On the other hand, IFM practices that increase the resilience of forests (e.g., to catastrophic wildfire, pest outbreaks, or increasing frequency and severity of drought) help to avoid emissions that would otherwise occur from disturbance.

For IFM, these two dimensions are closely linked. A practice that sequesters more carbon in the short term is not so valuable if the forest's resilience to catastrophic disturbance is compromised in the future. A recent and salient example is the loss of California Air Resources Board carbon offset projects to wildfire at a much higher rate than originally accounted for.[129] Clearly resilience and avoided emissions must be considered alongside direct removals in any IFM strategy.

Leakage. Another major challenge for IFM practices, particularly for managed forests, is the issue of leakage. Changes to management practices, such as reducing harvest volume per year, will create short-term and possibly long-term supply shocks that could very well be met by increasing supply from other forests elsewhere in the U.S. or abroad. It is critical that measurement and modeling of the benefits of IFM practices account for leakage.

Clarifying which IFM practices should be implemented where. The menu for IFM practices is extensive. It would benefit from consolidated and clear guidance from the USDA. IFM encompasses practices as diverse as enhancing recovery following a disturbance (e.g., the alteration of forest structure or composition to reduce risk of and mortality from wildfire) to enhancing sequestration capacity (e.g., the favoring of species or genotypes that are expected to be better suited for future conditions).[130] Different IFM practices will be suitable for different forest types and conditions, and results will vary based on a number of factors.

As an example, in October 2022, Verra and the American Forest Foundation published a new methodology (VM0045) for measuring IFM practices against dynamic matched baselines using the National Forest Inventories. While direct measurement of dynamic baselines is an excellent improvement over protocols that require growth and yield modeling, the protocol is completely open-ended with respect to which IFM practices to deploy, allowing, without restriction, any "intervention expected to achieve improved net carbon emission outcomes relative to business-as-usual practices."[131]

Clarifying which IFM practices are "expected to achieve" these outcomes, to what extent, with how much certainty, and in which forest types and conditions, are all areas in which science-based guidance from the USDA would help forest managers and policy makers navigate those complexities to ensure the optimal practices are correctly implemented in the right forests.

More precise modeling through better data on specific practices. Models of climate mitigation potential of IFM practices vary widely in their estimates. A more reliable and consistent mechanism must be created to measure trusted IFM methods when deployed in practice. The first step is to undertake sufficient MRV to demonstrate positive carbon sequestration results on a practice-by-practice basis, using a combination of remote sensing capabilities, machine learning, and ground truth data. Once practices are proven effective, tracking those practices and quantifying their benefits via modeling could be more efficient and effective than ground truth measurement. Models like the Canadian CBM (discussed Section II, above) are one such solution. MRV based on modeling – strengthened and verified with in situ measurements – offers the most effective path toward supporting IFM adoption and accurately measuring impacts.

To correctly identify and prioritize forest management practices for adoption in U.S. forests, it is critical that we fill knowledge gaps around the accurate quantification of benefits due to specific IFM practices. This includes both individually and in combination with other practices, in varied forest types and ecoregions, and under a variety of potential future climate conditions and natural disturbance regimes. The knowledge gaps are even more pronounced for belowground biomass and soil carbon modeling. They should be tested both alone and in combination with other practices, as well as in specific ecosystems and with an eye to changing climate conditions. And the Forest Service should point to those studies that are most trustworthy and fund others to fill gaps in our knowledge.

Carbon models for IFM practices will only be as good as their data inputs. In particular, three different types of spatially referenced time series data are needed: (1) stocking data (e.g. forest inventories to measure carbon stocks in the forest over time, in all relevant forest carbon pools, including soils); (2) activities data (records of all management activities over time, e.g. timber sale tallies, silvicultural prescriptions, and management plans); and (3) products data (information about the final uses of harvested material from each activity).

Critically, to derive statistical insight from these data, all three types must be integrated and linked in space and time. An ideal dataset would contain time series data on stocking, activities, and production on a specific parcel. This is a difficult problem to solve because sampling methods are different for each of these three data types.

We discuss the need for improvements in collection of these types of data in the FIA section above. Here there is a large role for remote sensing to play in generating stocking data. In addition, reliable practices / activities data will be critical. Commercial timberland managers typically collect both high quality activity and stocking data from their holdings, but these datasets are not usually available to the public or researchers. Access to this data would be greatly beneficial for modeling and research efforts of IFM practice efficacy across a wide range of commercial forest types. One key challenge is to encourage private landowners and forest managers to make such data available publicly without placing undue burden on these landowners and while protecting proprietary information.

Based on these observations, we recommend that the USDA and the Forest Service:

- **Lead efforts to gather and manage data on IFM practices and guide further research.** For a more detailed discussion on this point, see Section II, above.

- **Incorporate certain well validated IFM practices into requirements for USDA conservation grants and other project funding.** Given the urgency of the climate crisis, we recommend an iterative, act-and-adapt approach, where implementation and validation occur side-by-side. To get started, the USDA may focus on one or two high-value, relatively well-documented practices (such as extended commercial rotations and wildfire mitigation), tying adoption of these practices directly into requirements for grant programs such as the Forest Legacy Program, EQIP, NRCS Land and Water Conservation Fund grants, and the Urban and Community Forestry program. Easement purchases should explicitly include requirements for climate-smart forestry practices, and grants should explicitly provide funding for implementation of identified IFM practices. Grant applications that include IFM practices should be given preference over those that do not. And the USDA can partner with states to help them implement changes to their current use tax programs that incorporate requirements for IFM implementation.

  - Program participants that agree to enact these IFM practices could be obligated to report inventory and management data in a standardized format in order to receive benefits under the relevant program. That data, in turn, could be processed, aggregated, and published by the USDA or another agency as an input to further study on IFM practice efficacy, which in turn can inform revisions to IFM standards in those same programs on an iterative basis.

- **Support the development of Federal procurement standards and private certifications to incentivize IFM practices.** One way to reduce leakage issues from IFM is to create more demand for IFM practices from consumers**.** Procurement standards for the Federal government construction projects should explicitly include building with wood (including mass timber), and a clear preference to, where possible, source materials from forests being managed with IFM practices. (This topic is discussed in more detail in the long-lived wood products section that follows.)

  - **To the extent that the USDA and others assemble more data on IFM practices and their effectiveness, they should proactively share these data with standards boards**, such as the Sustainable Forestry Initiative, the Forest Stewardship Council, and the American Tree Farm system.
  - **The USDA and other agencies should actively push for development of private certifications for climate-smart IFM practices, and where possible researchers should work to independently validate such certifications to increase consumer confidence.**

- **The USDA should study ways to effectively measure holistic additionality, leakage, and permanence issues associated with IFM practices, especially for extended harvest cycles.** A systems-level approach is needed for accurate modeling of practices and to design appropriate safeguards to ensure that longer rotations in one area do not lead to harmful practices somewhere else, to account for management effects on soil carbon and other pools, and to capture the importance of managing for resilience vs. simply for greater sequestration.

- **Ensure that a portion of the IRA's $19.5B for NRCS conservation programs is allocated toward IFM practices on *forest* land,** and not just on agricultural land. We also recommend some portion of the $300M of IRA funding allocated for measurement and monitoring be put toward developing data collection and processing capability for these grant programs and other research around IFM practice efficacy.

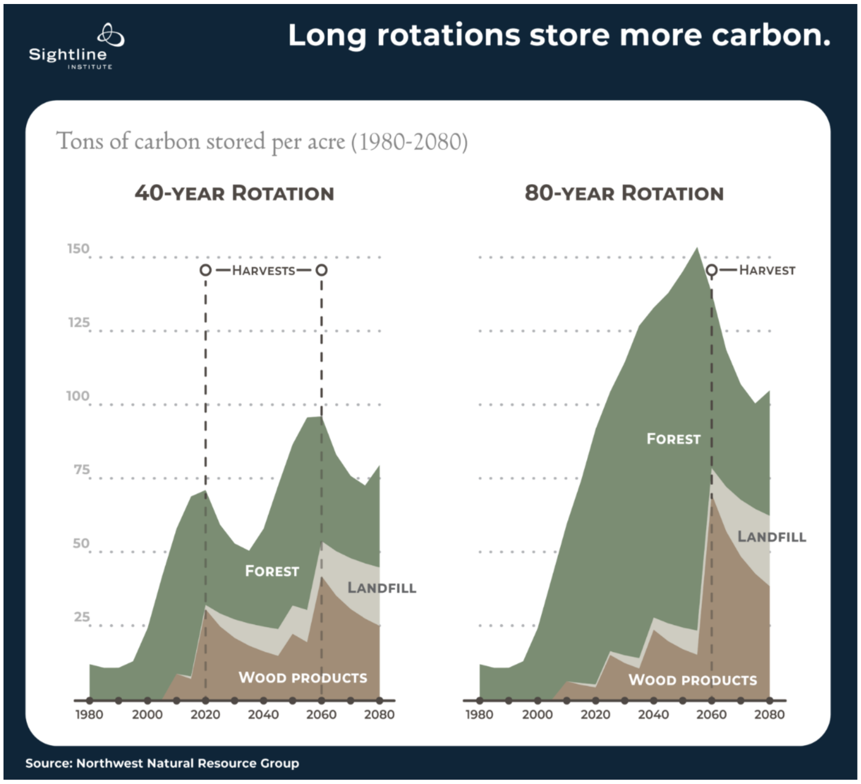
- **Train foresters and loggers to better implement and measure state-of-the-art IFM practices.** The Forest Service may benefit from enhanced partnership with a non-governmental partner, such as the American Forest Foundation, and support may take the form of assistance for equipment purchasing, training, or insurance.

To provide additional context for these recommendations, we highlight MRV and other implementation issues associated with illustrative IFM practices: extended harvest rotations; wildfire mitigation; and forest soil carbon enhancement. These practices are highlighted as examples of IFM practices—and not to limit consideration of holistic IFM practices that can include multiple features.

IFM Practice #1: Extended harvest rotations.

Extended harvest rotations are already in use and offer a model for quantifying the impact of other IFM practices.[132] Extended rotations refer to the practice of harvesting years, sometimes decades, later than foresters otherwise would. In working forests, extended rotations can increase permanent carbon stocking, on average, and they also support wood production of equal or greater economic value (based on quantity and quality of harvest, see figure below).[133] Other studies have pointed to enhanced soil carbon sequestration, due to less soil disturbance,[134] as well as improved biodiversity. Based on these conclusions, extended harvest cycles have for years been providing a source of credits in carbon market protocols like California.[135]

An illustration of carbon stocks in a typical vs. extended rotation Douglas-fir forest.[136]



Carbon storage from a southwest Washington Douglas-fir forest. Source: Northwest Natural Resource Group

The potential carbon benefits of extended rotations are, on the one hand, relatively easy to model, as growth and yield models developed for timber management have been well studied and validated over many years and many different forest types. Tools like the Forest Vegetation Simulator (FVS) can simulate changes in stocking for highly varied forest conditions and management scenarios, including rotation age and silvicultural treatment. Moreover, because commercial timberland managers tend to plan rotations that will maximize NPV, estimating “BAU” for a parcel with extended rotations is fairly straightforward.

On the other hand, these growth and yield models are based on historical data and may not have external validity under future climate conditions and disturbance regimes. In addition, there is a great deal of heterogeneity and local specificity. Beyond just the number of years of extended rotations, there are many other economic and management decisions that will affect stocking — notably thinnings or timber stand improvement between harvests — and many exogenous factors (cost of capital, access to wood products markets, local and global demand for wood products and carbon offsets, access to labor, risk of drought/fire/pestilence, etc.) that influence those decisions.

Finally, extended harvest cycles could result in net emissions compared to BAU in certain regions, especially where there is a high risk of catastrophic fire, pestilence, or prolonged drought. In these cases, harvesting trees earlier could, on average, help to (a) reduce eventual mortality from disturbance events, and (b) “bank” more carbon in long-lived wood products before it can be emitted due to mortality in the forest. It is critical that models for extended rotations use an objective function that includes *long-term* carbon stocking and not just short-term sequestration, and that these models account for current and future disturbance regimes.

Extending rotations is only a viable strategy for improved forest management in *managed* forests. Nearly all managed forests aim to derive at least some income from their harvests, even if only to cover operating costs. Deferring harvests and lengthening rotations, therefore, comes at an economic cost to the landowner in the short run, even though harvesting larger-dimensional, higher-grade timber from extended rotations may generate more revenue in the long run. This short-term revenue shortfall is an appealing target for policy interventions that seek to apply incentives and appropriate support for landowners to shift their rotation ages.

Extended harvest cycle recommendations:

- **The USDA should sponsor a pilot program to provide bridge funding for extended rotations in appropriate forest types to larger commercial landowners through the Climate Smart Commodities Partnerships Program.** Through a grant, a tax benefit, or even a low-interest long-term loan, the USDA can incentivize these forest managers to lengthen rotations and bridge the short-run gap from deferred harvest revenues. Funding should be contingent on reporting data on inventories, harvest volumes, and silvicultural practices back to the USDA for further study.

- **The USDA and the Department of the Interior should begin implementing extended rotations on their own managed forests and start conducting "BACI" (Before-After-Control-Impact) type studies wherever forest management occurs on USDA and DOI lands**, to study the outcomes across a range of forest types and conditions over an appropriate time scale.

IFM Practice #2: Wildfire Mitigation Practices.

Forest managers use many different mitigation measures to help prevent wildfires. Commonly used tools include prescribed burns, mechanical thinning, and fuel breaks. Prescribed burning involves setting controlled fires that are designed to mimic natural fires that burn through forests, cleaning out dead and overgrown vegetation while leaving the rest of the forest intact. Other areas can be subjected to mechanical thinning, which involves removing "hazardous fuels" that have grown up over time including smaller diameter trees and other undergrowth. Fuel breaks and fire lines also strip vegetation down to fire resistant species or remove vegetation entirely to keep wildfires contained or allow access lanes for firefighters. Multiple practices may be deployed in treated areas.

There is increasing confirmation that deploying wildfire mitigation tools can successfully reduce the risk of catastrophic wildfire.[137] The Caldor Fire in Lake Tahoe provides a recent example of one such success. The Caldor wildfire blazed through areas in which fires had been suppressed since the 1940s, burning massive amounts of collected vegetation. When the fire reached forest lands that had been treated with either prescribed burns or mechanical thinning, however, the fire slowed down, allowing firefighters to contain it.[138] Likewise, when it reached areas that had been treated, the Bootleg Fire in Oregon weakened appreciably, enabling firefighters to move in."[139] In addition to the safety and carbon benefits of wildfire mitigation, these practices can lead to improved air quality, rural jobs, and habitat protection. These benefits are further discussed in Appendix H.

Image showing where treated forested areas in Oregon stopped the Bootleg Fire[140]

While these mitigation efforts are key to avoiding the massive, unnaturally hot burning and destructive catastrophic fires that are fed by the build-up of hazardous fuels, they involve expensive, labor-intensive, and challenging processes. Mechanical thinning, fuel breaks, and fire lines often need to be deployed in hard to access areas and they typically produce significant amounts of low quality, low value wood. Prescribed fires can be difficult to manage and have the potential to cause great harm if and when they get out of control. As seen in New Mexico in 2022, losing control of a prescribed burn can cause significant damage and create a public backlash.[141]

Measuring and Monitoring Carbon Emissions from Wildfires and Wildfire Mitigation Activities.

The substantial new financial resources that are being allocated to the wildfire mitigation IFM provide an important opportunity to confirm the net carbon advantage that is presumed to be gained through the removal of hazardous fuels and its attendant carbon losses on the one hand and, on the other hand, the avoided carbon mega-emissions associated with the larger and more intense wildfires that are occurring in untreated forest areas.

There is no question that catastrophic wildfires cause massive carbon emissions. Emissions from catastrophic wildfires in 2021 may have accounted for nearly a quarter of global emissions.[142] But scientists have not be able to generate emissions estimates within a narrow band of uncertainty.[143] Recently, however, CTrees.org has opened up an exciting new avenue for measuring wildfire emissions based on its use of remote sensing and machine learning capabilities.[144] Determining the carbon emissions avoided by mitigation also has been challenging.[145] Given the high-end emissions risks of not treating hazardous fuel levels in forests, however, it is essential to improve how we use MRV to quantify wildfire emissions, and to estimate net avoided emissions from engaging in wildfire mitigation-related IFM practices.

Given the primary role that the federal government has in managing wildfires and the billions of dollars that it is spending on wildfire mitigation activities, the federal government should take the lead in developing an accurate and repeatable carbon emissions measurement process for wildfires, and for wildfire mitigation activities that are designed to reduce the nature and scope of wildfires.

The end goal should be robust and routine accounting of carbon benefits from fire treatment practices. Comparing the emissions from wildfires with those from prescribed and natural fires, and the carbon stored on treated lands, would give the federal authorities and researchers a granular data set indicating the relative carbon value of wildfire mitigation — including carbon emissions generated from the mitigation practices themselves. Thinned materials removed from forests will themselves have carbon profiles that will vary depending upon their end use.[146] Removed woody materials may be burned on site, combusted for fuel, incorporated into wood products (e.g., as incentivized under the Forest Service's Wood Innovation Grant Program, which promotes new uses for wood removed as part of ecosystem restoration and fire mitigation, including in biochar applications.)[147]

This information could help inform governments of the carbon cost of unchecked wildfires and indicate the carbon value of mitigation efforts that, in turn, can be used to prioritize public and private spending on such mitigation efforts.

Wildfire mitigation recommendations:

- **Better MRV should be developed to measure wildfire carbon emissions and the beneficial effects of mitigation practices on carbon emissions.**

The USDA and Forest Service should convene experts to develop a repeatable carbon emissions measurement and monitoring process for wildfire mitigation practices. The end goal should be robust and routine accounting of carbon emissions from wildfires and a corollary evaluation of potential net benefits from fire treatment practices. The work could be expanded to areas susceptible to pests and disease as well. Data should be made publicly available for use by academic researchers, state and local governments, and private industry. Measurement practices should be updated regularly as technology improves.

As data are generated and improved, it should inform all aspects of wildfire mitigation activity including by providing new inputs into the wildfire risk analysis that the Forest Service and the Department of the Interior are using to prioritize areas for treatment.[148] Having better information about carbon losses associated with woody materials that are removed from forests as wildfire mitigation measures also could influence the disposition of those materials. Location-specific factors will be critical.[149] Where feasible, alternatives to the on-site burning of woody materials—and the immediate injection of carbon dioxide into the atmosphere—should be considered. For example, as discussed in the next section, incorporating small diameter trees and other woody materials into long-lived wood products via cross-lamination and other wood product production processes, may generate a better climate benefit.[150] Likewise, converting wood waste into biochar that, in turn, may help increase carbon content in forest soils—as the Forest Service is now doing on a limited basis[151] —could be an attractive alternative to burning.

- **The Federal government should partner with local and state governments, private landowners, private industry, and tribal governments to get the most out of wildfire mitigation.**

Although the federal government plays a major role in fighting wildfires and in working to reduce wildfire risks by funding wildfire mitigation practices, it cannot do this work alone. The federal government only manages 31% of U.S. forests; a majority of U.S. forests are privately owned[152] and wildfires do not respect jurisdictional boundaries. As a result, to get the best results, the federal government needs to work closely with private, state, and tribal actors when assessing high risk areas and helping to implement wildfire mitigation activities in those areas.

For example, the aforementioned treated area in Oregon that helped stop the Bootleg Fire was owned by the Nature Conservancy and managed with the help of local Klamath Tribes.[153] Similarly, twenty-one state, local, tribal, and federal agencies had worked together to implement the successful mitigation projects that stopped the Caldor Fire.[154]

Partnerships also can help facilitate the more timely availability of funding to remove hazardous fuels from areas that are at high risk of catastrophic fire. For example, with the help of a USDA award from the Wood Innovation Grant Program, a non-profit financial institution — Blue Forests — issued forest mitigation bonds that enabled private foresters to thin forests without waiting for government grants.[155] This creative financing mechanism accelerated time-sensitive forest mitigation efforts.

IFM Practice #3: Enhancing Forest Soil Carbon.

While we have paid specific attention to aboveground biomass, forest carbon storage in North America must also include consideration of forest soils. According to the Forest Service, "in temperate forest ecosystems, the amount of carbon stored in soils is often greater than the amount stored aboveground in living and dead plant biomass," and large aboveground carbon stocks do not necessarily correlate to large carbon stocks below the ground.[156] Additionally, soil carbon stocks vary significantly by forest type in North America, with highest potentials for belowground carbon storage per unit area found in forest types prevalent in the East and Southeast/Southwest— regions with predominantly privately owned, working forests. Therefore, incorporating practices that improve soil carbon retention and sequestration will be a crucial piece of the puzzle when evaluating and supporting adoption of IFM. To that end, additional long-term field experiments are needed, particularly in ecosystems other than northern temperate and boreal forests, particularly given the high potential of southern forests.[157]

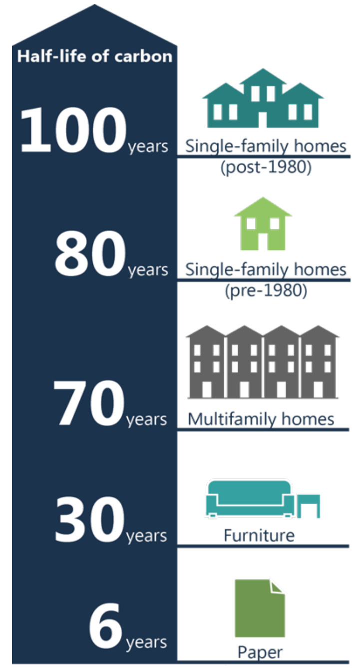
To illustrate, an IFM practice that has recently begun to be better appreciated is the addition of soil amendments. Biochar, which is discussed below, is a soil amendment that enhances soil fertility, sequesters carbon underground, and improves productivity by boosting water retention, nutrient availability, biological activity, and soil aeration, while also capturing toxic heavy metals.

Because otherwise unwanted forest trimmings can be — and in fact, are being — converted into biochar in some locations, the Forest Service is in an ideal position to test whether the addition of biochar to forest soils could help sequester additional carbon in forest soils, at the same time it removes the bulk of the carbon from unwanted forest trimmings into the biochar itself.

Longstanding research has established that nitrogen addition through fertilization or inclusion of N-fixing plants consistently increases soil carbon stocks across a wide range of forest ecosystems.[158] Reviews of the existing literature have shown that the only practice that meaningfully and reliably contributes to higher soil carbon stocks is addition of nitrogen, such as through nitrogenous fertilizers.[159] The impact of nitrogen addition can both improve the production of aboveground forest biomass and slow the rate of late stage decomposition processes that releases carbon.[160]

Despite research demonstrating the carbon benefits of nitrogen addition, however, more research is needed to understand the carbon impact of producing and applying the nitrogenous fertilizers themselves, and whether the net effect of soil amendments is carbon negative. An alternative approach to explore would be the selection of species with nitrogen-fixing associates in the soil such as Acacia, Alnus, and Ceanothus, which have similarly demonstrated soil carbon benefits in the long term, particularly on degraded sites.[161] That said, more study is needed to understand the potential for increased carbon sequestration to be offset by release of nitrous oxide in these systems.

E. Carbon Storage in Long-Lived Wood Products

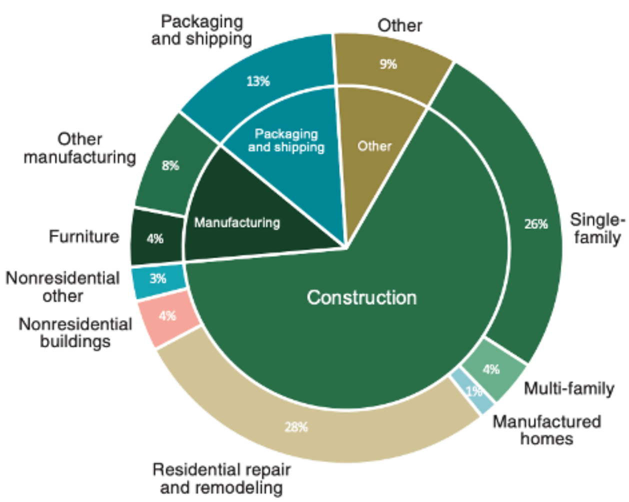


Increasing the quantity of sequestered carbon that is fashioned into long-lived wood products is another climate-smart forestry strategy that has the potential to keep forest carbon out of the atmosphere for several decades, or whatever the life of such products might be.

The expected life of wood products can vary significantly by product type. *See* graphic (from endnote 162). The Forest Service used internal data and research to estimate the half-life of carbon at 70-100 years for homes, 30 years for furniture, and 6 years for free-sheet paper.[162] The World Wildlife Fund (WWF) and Quantis generated a dynamic life cycle analysis (LCA) modeling tool that uses more conservative estimates on longevity —50 years for building materials, 16 years for furnishing, and 1 to 6 years for paper or packaging.[163]

The construction sector—which utilizes wood as a primary construction material because of its longevity (among other attributes)—accounts for approximately 66% of timber consumption. This includes traditional board timber, as well as so-called "mass timber" applications. Mass timber uses cross-lamination and other techniques to make particularly strong building materials where the wood and its sequestered carbon can substitute for energy-intensive materials like cement and steel, which are the source of 8% and 7% of global emissions respectively.[164]

Manufacturing (e.g., furniture), packing and shipping, and "other" uses (e.g., paper) account for the remainder of (less) "long-lived" wood products.[165] Growing in popularity is the conversion of woody material into biochar, which is a long-lived product that can itself enhance further carbon removal.



Solid wood products consumption by end-use market, 2019. Sources: APA (2019); CPA (2019); Howard & Liang (2019); MHI (2019); U.S. Census (2020b, 2020i); WWPA (2020).

A smaller but not insubstantial percentage of wood is burned—primarily for energy in connection with the harvesting and/or wood products manufacturing processes but also in lesser amounts to generate electricity (e.g., via wood pellets) or for heating purposes.[166]

In the United States, forest products are estimated to create 950,000 jobs with products worth $300 billion annually.[167] Nationwide, 89% of forest products come from private lands.[168] Timber harvest levels are 3-4 times higher in the South than the North or Pacific, with the Rockies accounting for a substantially smaller share of timber production.[169]

Quantification of MRV: Data and Protocol Practices and Barriers.

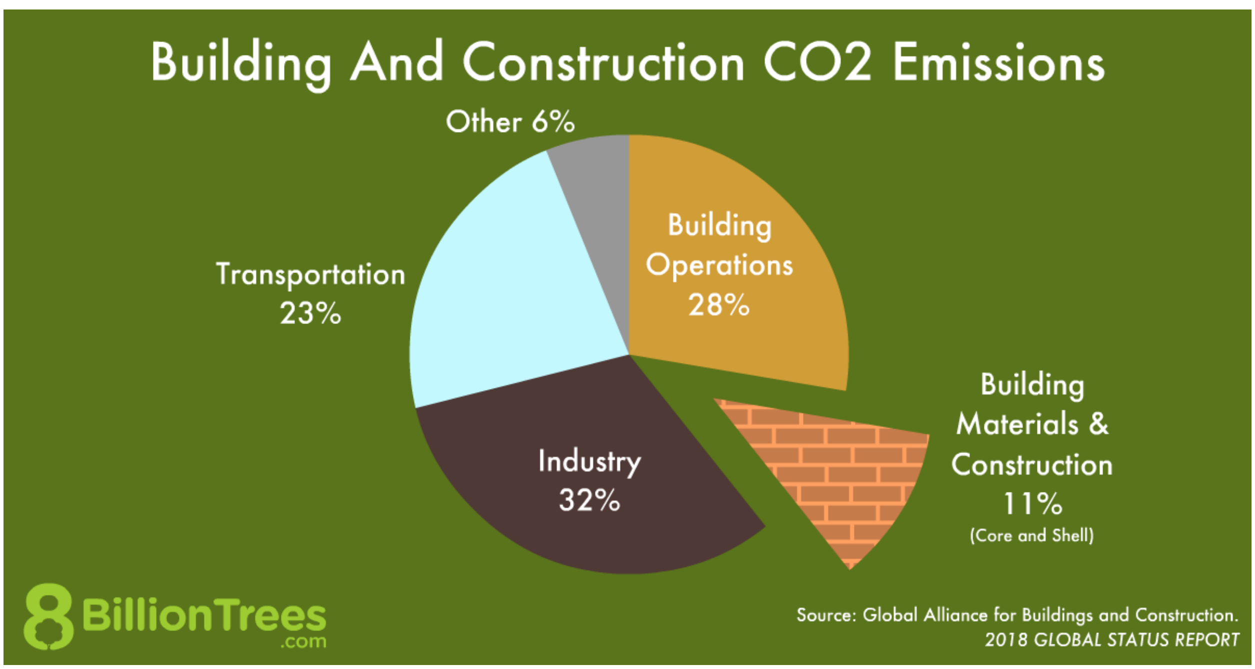
Carbon storage per unit of wood harvested is relatively easy to identify. This has been measured at the species-climate level and provides an input to life-cycle assessment (LCA) approaches. Pairing these per kilogram measures with global and domestic trade data, stakeholders have triangulated the potential annual impact of wood products with a fair amount of accuracy. For example, in 2021, the EPA reported that harvested wood accounted for an annual net negative flux of 102.8 MMT CO_2, making up a substantial portion of the estimated total annual removal of 592.5 MMT CO_2 from the U.S. forest ecosystem more broadly.[170]

Beyond a top-line estimate of carbon storage duration, environmental product disclosures (EPD) are being used with growing frequency to identify embodied carbon totals in a variety of products—ranging from steel and concrete to wood products—that incorporate LCA inputs. To be accurate, LCAs must consider upstream energy and carbon costs, which in this case extend from forest production practices through end-of-life planning.[171]

As a general matter, when LCAs connected to forestry production are incorporated into EPDs for wood products, the EPDs reinforce the relative advantages of wood products by, for example, underscoring the lower energy input required for the nature-based production of timber for construction as compared to steel or concrete — with one meta-analysis of 100 case studies on residential buildings finding 28-47% lower embodied emissions of timber buildings compared to concrete and steel.[172] It should be noted, however, that EPDs can generate inconsistent results given gaps regarding localized upstream emissions (which are closely tied to forest production practices), a lack of comparability across products, and inconsistent rules on reporting formats.[173]

Incentivizing Long-Lived Wood Products

There is significant policy interest in lowering the building sector's carbon footprint, insofar as buildings are responsible for up to 40 percent of all greenhouse gas emissions. Approximately one-third of buildings-related emissions are attributable to "infrastructure materials and construction" — typically referred to as "embodied carbon" — with the other two-thirds tagged to building operations (heating and cooling, etc.).[174] As a result, the increased use of long-lived forest products in lieu of energy-intensive, high-embodied carbon building materials potentially could play a key role in helping to decarbonize the buildings sector.



Heightened concerns about climate change and the need to reduce overall emissions is prompting public policy moves to incentivize the increased use of long-lived wood products in the construction industry. In particular, federal and state leaders are increasingly using the procurement process to preferentially purchase lower embodied carbon building materials. Not only does this reduce their carbon footprints, but it also sends a market signal that spurs changes across the industry.[175]

Initially, state governments led the way,[176] but in the last two years the federal government and the Congress have moved aggressively to promote the utilization of low embodied carbon building materials. The White House established the Buy Clean Task Force in December 2021, with an initial focus on lower-carbon construction materials in federal construction and agency procurement.[177] A series of Administration actions in 2022, led by the General Services Administration (GSA), began to actuate consideration of lower embodied carbon when procuring building materials for federal construction. In particular, the GSA issued procurement standards that require EPDs for all concrete and asphalt mixes.[178] It also identified "structural engineered wood" as a material to be reviewed in the future after aluminum, insulation, commercial roofing, and gypsum board.[179]

Next, Congress upped the ante in August of 2022 when it authorized and appropriated several billion dollars in the Inflation Reduction Act for GSA, FEMA and the Federal Highway Administration. This funding is for agencies to utilize low carbon materials in construction projects and for the EPA to develop and implement an EPD program that includes EPD labeling for lower-carbon construction materials.[180]

In addition to procurement directives and funding allocations, building codes are expanding provisions for mass timber.[181] The 2021 International Building Code, for example, includes three new construction types that allow the use of mass timber in buildings up to18 stories. Many states already have adopted this new building code, which removes previous code restrictions on constructing tall buildings from mass timber.[182] Also, California recently enacted AB 2446, which tasked regulators (in this case, the California Air Resources Board) with developing a framework for measuring the embodied carbon of building materials and a strategy to reduce emissions in the construction sector by 40% by 2035.[183]

It is important to couple incentives for the increased utilization of long-lived wood products with upstream forestry practices that embrace Improved Forest Management, as discussed in the IFM section above. Having respected standard-setting organizations such as the Sustainable Forestry Initiative, the Forest Stewardship Council, and the American Tree Farm system explicitly link IFM practices with long-lived wood products whose origins they otherwise are endorsing would reinforce this important protection. It also would be important to extend these protections to long-lived wood products made from imported wood.[184]

Thus, as discussed above, we recommend:

- **Procurement standards for the Federal government construction projects should explicitly include building with wood (including mass timber), and a clear preference to, where possible, source materials from forests being managed with IFM practices.**

- **To the extent that the USDA and others assemble more data on IFM practices and their effectiveness, they should proactively share these data with standards boards such as the Sustainable Forestry Initiative, the Forest Stewardship Council, and the American Tree Farm system, and with this data the USDA and other agencies should actively push for development of private certifications for climate-smart IFM practices.** Where possible, Forest Service researchers should work to independently validate such certifications to increase consumer confidence.

We also recommend that the USDA adopt these additional recommendations that flow from our consideration of long-lived wood products:

- **Commission a respected entity, like the National Academy of Sciences, to prepare a definitive report that addresses the relative carbon benefits of wood products as compared to other building materials.** Ensure adequate expertise for reporting to factor in macroeconomic trends and broader land use impacts, particularly concerns around leakage and double counting.

- **Leverage the Federal 'Buy Clean' initiative to prioritize procurement standards that encourage the use of long-lived wood products, noting that these efforts will not only guide federal procurement but serve as a model for states, the private sector, and industry players. Consider additional policy levers, such as subsidies or tax benefits, to encourage responsible expansion of supply and adoption of mass timber.**

- **Use the IRA's $250 million allocated to the EPA for EPDs to develop protocols for wood products that are rooted in data not only about the products themselves but also IFM and end of life planning.** This will establish a credible link between wood products from working forests and the voluntary carbon offset project methodologies for IFM. **Align with the Partnerships for Climate-Smart Commodities program to ensure meaningful data and trustworthy methodologies are rooted in data and in practice.**

- **Support private landowners' efforts to monetize additional carbon benefits from wood produced on their land, particularly for small, family ownerships and minority landowners.** For example, AFF's $35 million grant through Partnerships for Climate-Smart Commodities will fund the "Engaging Family Forests to Improve Climate-Smart Commodities" project. Recognizing that less than 1% of carbon market lands are in small, family ownerships, the program assists minority landowners on privately held land by supporting implementation of IFM, measuring outcomes, and developing mechanisms to trace wood products to market for VCM benefits.[185]

As a final note, while government agencies, private entities, and trade organizations frequently promote long-lived wood products as a job-creating opportunity to work toward net zero goals,[186] a considerable number of experts are tempering expectations and encouraging additional study of the impact of long-lived wood products on the broader economy. These include concerns with product substitution or displacement, asking whether incentivizing mass timber might increase total consumption, and questioning what exactly is being displaced.[187] They also caution against the risk of double-counting, where both foresters and product manufacturers may receive credits for the same abated carbon.[188] Where carbon credits are involved, a significant concern involves establishing additionality.[189] And, while the construction sector represents a major source of emissions and is accordingly highlighted as a major opportunity to substitute concrete or steel with wood products, other wood product uses represent a significantly smaller market size with less clear emissions reduction benefits.

A Word on Biochar: An Unconventional, Climate-Friendly and Exceptionally Long-Lived Wood Product.

Biochar production involves the thermal decomposition of biomass in an oxygen-limited environment, a self-fueling process that results in a stable carbon-rich material. Biochar refers to the solid form, produced at lower temperatures, while bio-oil is the liquid form, created in a fast, high heat process.

From a climate mitigation point of view, biochar has been estimated to have the potential to capture approximately one ton of carbon per hectare of agricultural land per year (when crop biomass is used as a feedstock).[190] Globally, biochar systems could deliver emission reductions of 3.4-6.3 $GtCO_2e$, half of which constitutes CO_2 removal.[191] Biochar and bio-oil are highly recalcitrant, they do not easily decay, and thus can sequester organic carbon for the long term, potentially for centuries. Another advantage of biochar is that it does not create competition for land and uses waste streams as a feedstock, minimizing potential leakages.

Finally, the fact that over 50% of the carbon in the biomass can be retained confirms the additionality of this process compared to the baseline of burning or creating other wood products.[192] Bio-oil can contain even more of the biomass carbon and can use waste feedstocks unsuitable for soil application. The product can either be refined and used in a variety of products, or even injected underground as a carbon storage strategy.[193]

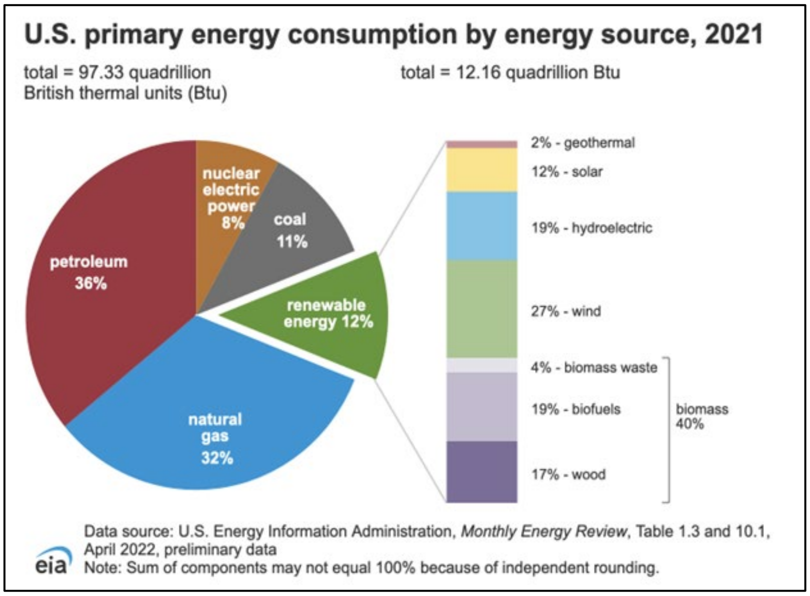
As a climate adaptation strategy, biochar comes with a substantial list of co-benefits for both producers and the environment. When added to soil, biochar enhances soil fertility, sequesters carbon underground, and improves productivity by boosting water retention, nutrient availability, biological activity, and soil aeration, while also capturing toxic heavy metals.[194]

Finally, biochar and bio-oil can be burned to produce energy if necessary. Thus, there are compelling ways the carbon embodied in wood trimmings and waste products from the forestry sector (including, for example, from wildfire mitigation practices) can be embedded into improved forestry management practices. Soils in managed forests can be amended with long lived carbon in biochar, providing a host of ecological co-benefits and locking carbon away for potentially centuries.

F. Forestry-Derived Bioenergy with Carbon Capture & Storage (BECCS)

Bioenergy from Wood: Putting Its Potential in Context.

Bioenergy from woody biomass (wood and wood waste products–bark, chips, sawdust, etc.) represents a small share of total US energy production. And it's just a sliver of total U.S. energy consumption as well, making up 2.1% of usage in 2021. According to the Forest Service's 2020 RPA Assessment, fuelwood accounted for about 15% of U.S. roundwood harvests in 2016.



Unfortunately, wood is not a particularly efficient fuel for burning, due to its high moisture content. Per unit of energy produced, wood releases more carbon when burned than most grades of coal, while also releasing more particulate matter and other local pollutants. Researchers working with the Natural Resources Defense Council (NRDC) concluded that a wood-burning energy facility would have higher net carbon emissions than a comparable coal plant for the first 4 decades or more of operations.

Wood-based bioenergy is sometimes touted as "carbon neutral," based on the assumption that forests grow back over time and replace the biomass taken for fuel. These arguments overlook the fact that the carbon debt that is created by burning wood can take decades, or longer, to be "repaid" through the growth of new trees. Crucially, this means carbon levels will increase during the critical, near-term period when it is most urgent to limit new emissions, redouble efforts to increase sequestration, and reduce overall emissions.[195]

The Forestry BECCS Proposition

Creating energy from forest-based biomass and linking it with carbon capture and storage (BECCS) presents as a potentially-attractive mechanism to generate zero carbon energy from a nature-based source — forests — with the carbon being removed from the combustion stream and stored through a viable CCS (carbon capture and storage) process.

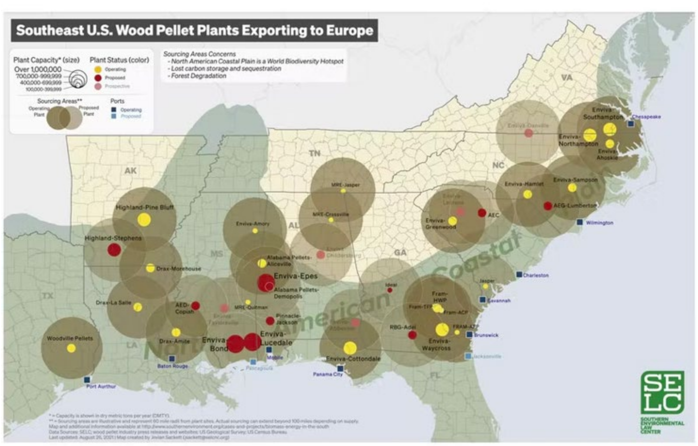
The U.S. is generating a large volume of bioenergy through corn-based ethanol production. As a result, it is the BECCS feedstock that has commanded the most attention to date. Indeed, the only current BECCS facility in operation in the U.S. today is an ethanol production facility in Illinois. But not for long. The Inflation Reduction Act included generous tax credits for CCS activities of all types, including biofuels. And the IRA's new clean electricity production credit (Section 45Y) specifically calls out BECCS as a focus technology.[196] Globally, 50 new BECCS projects were announced in 2021 and the first half of 2022, totaling 20 megatons of storage per year.[197]

Whether forest-based biomass might be a viable feedstock for BECCS project is an open question. The high cost of transporting large volumes of biomass feedstock has been, to date, a limiting factor in developing BECCS projects — keeping projects small, in the range of 10 megawatts, as compared to 250 megawatts for typical coal plants.[198] Viable BECCS facilities also must be in areas with access to sites suitable for underground injection and storage of carbon dioxide. Mapping the availability of quality feedstock against suitable injection and storage sites yields three regions within the United States that most experts consider potentially suitable for BECCS: the western Dakotas, northern Illinois (current site of a BECCS facility), and the Gulf region.[199]

Given these geographic considerations, woody material removed from forests as a wildfire mitigation measure is unlikely to be generated in adequate quantities near these the regions. The general assumption is that future BECCS plants in the Dakotas and Illinois would rely on agricultural-based biomass while the Gulf Region could rely on private forests that currently are supporting the paper and wood pellet industries.

The possibility that private foresters in the southeastern U.S. might grow and harvest trees to support BECCS facilities is no longer theoretical. UK-based wood pellets manufacturer Drax recently announced its intent to build two BECCS facilities in the southeastern U.S., taking advantage of the concentration of its existing pellet production plants there.[200] This is particularly notable given the pressure on Drax to stop shipping U.S.-based wood pellets across the Atlantic to the U.K. to generate electricity from wood pellets, which have been criticized for being neither a fully "renewable" or "sustainable" energy source.[201]

Potential Forestry-Based Feedstock Sources for Future BECCS Facilities	
Wood Pellet Production The wood pellet market has exploded in the past decade, in large part due to the E.U. classifying wood biomass as a renewable energy source and Asia's pivot from nuclear power after the 2011 Fukushima disaster.[202] While historically created from waste products of traditional timber productions, wood pellets are now in such high demand that whole trees are being planted and harvested for their production. The southeastern U.S. has become the epicenter of the wood-pellet export industry that has grown tenfold in 10 years–from almost nothing to 23 mills with capacity to produce 10 million metric tons annually for export.	**Smaller Scale Wildfire Management** Wildfire mitigation practices require thinning forests and generating biomass that may be suitable for bioenergy uses. The Forest Service partners with private companies to utilize thinned materials for bioenergy.[203] Carbon emissions from these facilities depend on several factors, including distance between the facility and the mitigation area and the extent to which sale of forest materials funds further mitigation.[204]



MRV and Leakage Issues for Forest-Based BECCS

Viewed in isolation, there do not appear to be any difficult MRV issues for forest-based BECCS projects. Forest biomass is primarily made up of carbon that potentially could be fully captured and stored via an efficient CCS process. This, after all, is the appeal of BECCS: it theoretically can enable nature-based biomass to produce energy without carbon consequence. Of course, if less than all the carbon is removed and put in geologic storage, MRV issues come into play.

Leakage issues pose a different kind of challenge for forest-based BECCS. If the BECCS market takes off based on forest biomass feedstock, it could increase demand for timber production to meet other needs, potentially leading to unsustainable logging activity in the U.S. or — perhaps more likely — overseas. To partially address this issue, it will be important link the use of forestry-based feedstocks for BECCS projects with the deployment of upstream climate-smart forestry practices.

V. APPENDICES

Appendix A

Measurement, Monitoring, Verification & Reporting Recommendations.

We recommend that the USDA and the Forest Service expand the FIA program to include remote sensing and machine learning capabilities; enhance the FIA program's field plot measurements; and deploy the FIA and other appropriate data and analytical tools to measure and monitor the carbon benefits of specific forestry practices. Having stronger data confirming carbon gains from specific practices will facilitate appropriate prioritization and incentivization of such practices.

In particular, the USDA and the Forest Service should:

- Invest in integrating new technologies, particularly new remote sensing and soil sampling technologies, to increase the density, frequency, and comprehensiveness of the FIA data base.
- Work with NRCS to use the Canadian CBM to quantify practice-level potential and carbon impact of various climate-smart forestry practices.
- Accelerate FIA effort to enhance sampling protocols that increase plot density and frequency and support fine-scale decision support.
- Coordinate with the White House and the U.S. Digital Service to integrate FIA plot data with remote-sensing and machine learning data inputs for specified climate-smart forestry practices and make this information broadly available in an anonymized format.
- Continue to innovate and emphasize collection of data beyond carbon and timber.

Agroforestry Recommendations.

- The USDA should substantially increase the budget and capability of the National Agroforestry Center (NAC) and charge it with: (1) obtaining census data regarding the nature and scope of agroforestry operations in place today in the U.S.; (2) addressing the significant gaps in MRV data and protocols for agroforestry by systematically identifying agroforestry practices by region and, for each, (a) obtaining and analyzing field-based and remote sensing data to evaluate carbon sequestration benefits (using tools developed in other forestry and agricultural contexts); and (b) developing qualitative and quantitative approaches for measuring agroforestry co-benefits.
- We recommend that the USDA and NRCS:
    - Set aside $1 billion of the $19.5 billion in the Inflation Reduction Act's conservation funding to incentivize the adoption of high-value agroforestry practices, targeting silvopasture and windbreaks.
    - Invest in capacity building and training extension agents.
    - Establish an "EarthShot" goal to drive a major agroforestry initiative that would:
        - iii. Create a Joint Chiefs' Agroforestry Initiative, modeled on the Joint Chiefs' Landscape Restoration Partnership, to align the NRCS and USFS/NAC in the pursuit of jointly-established agroforestry acreage targets, timelines to develop MRV and protocols, and technical support and outreach.
        - iv. Leverage partnerships to assist in scaling agroforestry.

Reforestation Recommendations.

- The MRV tools described above in Section II—including remote sensing and machine learning—should be applied to identify baseline conditions and to track and project anticipated reforestation carbon sequestration increases at the project level.
- The Forest Service and other federal land management agencies must accelerate attention on reforestation workforce issues by collaborating with other agencies and non-governmental organizations and investing in employees, contractors, and partners to scale reforestation efforts.
- The federal government should establish a national tree seed collection permit or MOU system for non-Federal organizations on Federal lands in line with recommendation 2.2 and 2.5 from the joint report issued by the Departments of Agriculture and Interior.

Urban Forestry Recommendations.

We recommend that the USDA and the Forest Service should:

- Partner with the U.S. Digital Service and other data management experts to develop new carbon measurement tools that take advantage of remote sensing capabilities and machine learning to generate carbon sequestration baselines and updates for urban forests. See Section II.
- Partner with states, cities, outside NGOs and forestry experts to develop a national urban tree spatial dataset. Creating a comprehensive dataset would facilitate the assessment of national goals, enable monitoring of canopy cover changes, track species composition, and measure shifts in carbon storage.
- Build into their grants data collection requirements that will enable the USDA to build and share a larger quantification data set that measures and monitors the carbon and other benefits associated with urban forestry investments including, but not limited to, equity, extreme heat, air quality, energy conservation, and urban hydrology.
- Ensure that its grantees use a co-production approach to decision-making which involves local communities, neighborhood associations, and NGOs. Thoughtful community engagement can help to bridge gaps between risk assessments and community preferences.
- Assist cities in utilizing locally adapted and native species; trees that are tolerant to environmental stress; and biodiverse tree mixes that will increase carbon sequestration and ecosystem resilience.

Improved Forest Management Practices (IFM) Recommendations.

We recommend that the USDA and the Forest Service:

- Lead efforts to gather and manage data on IFM practices and guide further research. For more detailed discussion, see Section II.
- Incorporate certain well validated IFM practices into requirements for USDA conservation grants and other project funding.
- Support the development of Federal procurement standards and private certifications to incentivize IFM practices.
- Study ways to effectively measure holistic additionality, leakage, and permanence issues associated with IFM practices (especially for extended harvest cycles).
- Ensure that a portion of the IRA's $19.5B for NRCS conservation programs is allocated toward IFM practices on *forest* land, and not just on agricultural land.
- Train foresters and loggers to better implement and measure state-of-the-art IFM practices.
- Additional recommendations regarding extended harvest cycle, wildfire mitigation, and forest carbon IFM practices are included in Section III, above.

Long-Lived Wood Products Recommendations:

We recommend that the USDA and the Forest Service:

- Commission a respected entity, like the National Academy of Sciences, to prepare a definitive report that addresses the relative carbon benefits of wood products as compared to other building materials. Ensure adequate expertise for reporting to factor in macroeconomic trends and broader land use impacts, particularly concerns around leakage and double-counting.
- Leverage the Federal 'Buy Clean' initiative to prioritize procurement standards that encourage the use of long-lived wood products, noting that these efforts will not only guide federal procurement but serve as a model for states, the private sector, and industry players. Consider additional policy levers, such as subsidies or tax benefits, to encourage responsible expansion of supply and adoption of mass timber.
- Use the IRA's $250 million allocated to the EPA for EPDs to develop protocols for wood products that are rooted in data not only about the products themselves but also IFM and end of life planning. This will establish a credible link between wood products from working forests and the voluntary carbon offset project methodologies for IFM. Align with the Partnerships for Climate-Smart Commodities program to ensure meaningful data and trustworthy methodologies are rooted in data and in practice.

- Support private landowners' efforts to monetize additional carbon benefits from wood produced on their land, particularly for small, family ownerships and minority landowners.

Appendix B

Although FIA has made major steps forward to advance research in remote sensing for tree inventories, these advances have not been integrated into the FIA data base. To address these challenges, we make five specific recommendations for steps the FIA can take to practically realize the potential efficiency and effectiveness gains from integration of **remote sensing**:

1. **The FIA should quantify efficiency improvements from a wide variety of potential integrations of remote sensing into FIA and prioritize implementing remote sensing initiatives that promise the greatest efficiency gains.** As documented in research produced by the FIA, remote sensing can drastically improve the "economic efficiency of the FIA survey [in three ways]. The first is by allowing FIA to meet NFI precision requirements with fewer field plots…. The second economic benefit of RS data integration is also related to adding value to the program, through investment in products that go beyond traditional inventory summaries and analyses…. A third benefit of RS data integration comes in the form of avoiding unnecessary field work." Within 3 to 6 months, the USDA should convene a panel of leading experts from FIA as well as academia and the private sector to identify and quantify exactly how much different opportunities for integrating remote sensing into FIA can (a) improve precision with fewer field plots; (b) increase the temporal frequency and spatial resolution of forest inventories with limited uncertainty; and (c) automate aspects of forest inventories where current remote sensing methods can achieve similar accuracy to field surveys.

   At the end of this process, the USDA should use the quantitative estimates of potential efficiency improvements to prioritize investment in 3 to 5 initiatives that have the greatest potential to reduce costs and add value for the FIA to implement over the next 5 years.

2. **To address the research feasibility challenges, we recommend that the USDA and the Forest Service work with CTrees.org to build on the BIGMAP project and develop code, training and evaluation datasets, pre-trained models, and scientific documentation for open-source remote sensing-based inventories of individual trees from high-resolution satellite imagery.** Despite being a major advance, BIGMAP's dependence on low-resolution Landsat imagery limits its usefulness beyond coarse applications, and the FIA should be using the best data and methods currently available. Remote sensing derived data products on U.S. forests should not only be using 30m resolution Landsat imagery, but also 50cm-resolution NAIP imagery, 3m resolution Planet Basemap Imagery, and 10m Sentinel Imagery, as all of these sources are cost-effective, cover the United States, and have a temporal frequency significantly greater than the FIA (5 years). The Ctrees.org team has demonstrated that machine learning models for forest monitoring at large scales can be combined with optical satellite imagery and FIA data to generate low-cost, high-resolution high-frequency inventory data, and the USDA should work with CTrees to expedite and integrate these advances into FIA.

3. **The Forest Service should anonymize, package, and distribute FIA data as the critical ground truth datasets needed by machine learning remote sensing models.** Research from the Forest Service has noted that "NFI data are invaluable to creating remote sensing products. They provide a standardized source of training data for models, and their use raises the likelihood that remote sensing-based estimates will align with NFI-based estimates. They also provide valuable validation data for users interested in conducting map accuracy assessments at both the plot-pixel scale, as well as over larger geographic areas like U.S. counties, for which NFI-based estimates and confidence intervals can be generated." To enable the research community to further reduce the costs of forest monitoring with advances in machine learning for remote sensing, FIA plot data should be packaged and distributed for researchers and practitioners of machine learning and remote sensing, as it would be a valuable dataset that would draw interest in the forest carbon data repository from a wide range of stakeholders in the private sector, academia, and open-source software developers.

4. **To address the capacity gaps in software infrastructure and remote sensing within FIA, we recommend that the USDA and the Forest Service work with the US Digital Service, hire new staff, and identify potential partners and contractors to develop the appropriate in-house capacity to more effectively realize improvements from new technologies into the FIA inventory.** Dramatic

improvements in remote sensing, cloud computing, and machine learning over the last 10 years call for an effort to significantly modernize FIA. FIA staff are already overstretched, and there is a need to invest in technical capacity to support and collaborate with staff within the Forest Service to modernize the FIA in an age of AI and remote sensing. Specifically, this task force should identify opportunities to make strategic hires of software engineers and data scientists to implement the needed methodologies and infrastructure to realize the potential of integrating remote sensing into FIA. FIA should also identify potential private sector contractors and technical partners to help improve capacity for implementing remote sensing-based improvements for FIA forest monitoring. To address the cost of operationalization and computing challenges, we recommend that the USDA and the Forest Service work with private sector partners who have developed free and open high-performance geospatial computing systems such as Google Earth Engine or Microsoft Planetary Computer to enable development and distribution of open-source remote sensing-based construction of data products on U.S. forests to be used by FIA and the Forest Service as well as the broader community.

5. **To address the need for nimbleness and creative investigation, we recommend that the USDA invest in hosting scientific conferences and data science competitions that engage actors from private sector, academia, and public sector on new methods in remote sensing and machine learning for monitoring forests, informed by what the Forest Service believes are the most important gaps for improving forest inventories in a changing climate.** The NEON Trees Data Science Challenge[205] played a critical role in catalyzing innovation and advances in remote sensing for forest monitoring. We believe this approach can help FIA engage with and better support the larger remote sensing of forests community, crowdsource the capacity for developing and implementing best methods and approaches for scalable forest monitoring with remote sensing, and maintain a close connection with and awareness of how the research community and private sector is pushing the frontier of how we can use AI to monitor forests.

Appendix C

The FIA receives a substantial amount of funding and in-kind support from partners, especially state forestry agencies and university research programs. FIA administrators have leveraged partnerships with a variety of strategic external partners to develop enhanced capabilities in the past, such as in vegetation classification and spatial mapping.[206] Pursuing new partnerships with a goal of developing remote sensing capabilities that integrate with FIA's existing plot data would be extremely valuable. Other potential partnerships with large land trusts or even with the public through citizen science campaigns could generate meaningful data, particularly around population centers. As noted above, mobile phone applications are being developed that allow a person with relatively little training to capture tree-level biometric data on their phone.

A particularly fruitful set of partnerships could come from commercial forest landowners. These companies typically collect high quality data on inventory (from which biomass and carbon can be easily estimated), silvicultural activities, and production/sale volumes. Currently, however, the FIA program is limited to the National Woodland Owners Survey data. While spatially linked to FIA plots, it does not provide granular detail on climate-smart forestry practices enacted or harvest volumes from the site. Moreover, data from the single FIA plot will not be as instructive as stand-level inventories conducted by the local forest manager that can be linked to silvicultural treatments and harvests over time.

Appendix D

AGROFORESTRY COMMODITIES
Case Study: Chestnuts

Why Chestnuts?
Once the foundation of many civilizations, Chestnuts are a resilient healthy nut crop capable of supplying a high-quality source of food, fodder, and industrial feedstocks. Trees can produce 2,000-3,000 pounds of chestnuts per acre while allowing for (1) alley crop production on over 75% of the same acre while trees are young; and (2) pasture livestock production when trees are mature. This productivity and high market price provide an attractive revenue opportunity for farmers who can earn a gross income of $50,000 to over $100,000 per year.[207]

Chestnuts have the capability of replacing corn in the eastern U.S. while providing an attractive revenue stream and a range of ecosystem benefits. Mature chestnut trees are prolific at capturing and storing carbon - more than 8 tons of carbon per acre. All the while, those roots are stabilizing the soil, capturing excess nutrients, and reducing pollution of surface waters.[208]

Market Potential.
The global market for chestnuts is $5.4 billion and is projected to increase by 3.1% annually over the next five years.[209] In the U.S. there is already a large unmet demand for chestnuts and the market applications for chestnuts are growing. The challenge is to help U.S. farmers meet this growing demand and capture part of this large market. At present, U.S. consumers eat 0.1 lb of chestnut per capita on an annual basis, while Europeans average 1.0 lb per capita. Koreans are the world's largest chestnut consumers at 4.0 lbs per capita.[210] Chestnuts sell for $.75 to $2.50 per lb wholesale.[211]

Chestnut Market Opportunity	Fresh Chestnuts .1 lbs/capita	Peeled/Frozen .5 lbs/capita	Flour, mixes 1 lb/capita	Neutraceuticals, Industrial uses
Target Volume (t)	20,000	82,000	200,000	10,000,000
Yield (lbs/acre)	40,000,000	164,000	400,000,000	20,000,000,000
Area (acres)	20,000	82,000	200,000	10,000,000
# Trees	960,000	3,936,000	9,600,000	480,000,000

What is needed to Scale.
There are several bottlenecks slowing the growth of this agroforestry commodity. The USDA, in partnership with chestnut grower associations, universities, and NGOS can develop collaborative approaches to fund and support chestnut research and industry development over the long-term. Specific areas in which the USDA can help include:

1. The USDA can provide incentives and technical assistance which, in turn, can help generate the catalytic capital needed to cover the 6-to-10-year time lag for a return on investment; and
2. The USDA's research arm can assist with genomic tools and clonal propagation to help increase the productivity of chestnut trees, potentially doubling chestnut tree yields.

Appendix E

Washington, D.C. provides an example of how urban forestry programs can reduce tree inequity. In 1999, a report by American Forests showed that there was a huge divestment in urban tree cover in Washington, D.C., especially in areas with rising poverty rates. This report and the media coverage that ensued led to the creation of the Urban Forest Administration, which focused on planting trees in Washington, D.C. neighborhoods that lacked cover. The initiative focused on planting in areas with the most need. It led to D.C. being one of the municipalities with the most equity in urban tree coverage.[212]

Another story of improved urban forestry is the Elaine Clegg City of Trees Challenge to plant 100,000 urban trees in Boise and one forest seedling in Idaho per Boise resident. Part of this stemmed from data showing the areas in Boise with fewer trees were far hotter during heat waves. After planting 15,000 urban trees and 149,000 forest seedlings, the benefits are estimated to accrue to over 39 million pounds of carbon removed, 312,000 pounds of air pollutants removed, 47.4 million kWh of energy conserved, and 121 million gallons of stormwater capture.[213] This project also shows the community building aspect of urban forestry programs. Residents could order and pick up the trees at their farmers market then plant it themselves. To help with urban heat islands, they also formed a volunteer program helping to spread word about the program, get the right trees in the right places, and educate residents about tree care.

The Boise and D.C. examples show not only the benefits of urban forestry but how it is possible to change the history of urban forestry with investments and community programs.

Appendix F

In response to projected increases in the frequency of heat waves, some cities have invested in developing and expanding green infrastructure before the recent federal funding influx. For example, Chicago, IL, has taken measures to identify populations vulnerable to extreme heat and eliminate these hotspots through increased tree canopy, planting over 500,000 trees since 1989.[214] Similarly, Miami, FL has committed to increasing tree canopy in pedestrian frequented areas, such as transit stops, pedestrian walkways, and schools.[215] Miami's local government has also partnered with Shading Dade, a citizen science initiative led by Florida International University in partnership with the University of Miami, to support community identified priorities.[216] Lastly, Phoenix, AZ, became the first U.S. city in 2021 to pledge tree equity in partnership with American Forests, committing to planting 100 cool corridors to bring city temperatures down and allocating $1.5 million from Phoenix's city council to support this initiative.[217] Through the Cool Corridors program, Phoenix aims to plant 200 trees per mile by 2030 with local communities.[218] These examples show that cities have bought into urban forestry and the new federal funding will help take urban forestry even further.

Appendix G

Additional Health benefits from Urban Forestry

Health. Beyond the evident health advantages resulting from decreased heat, urban forests offer a range of additional health benefits. While quantifying these benefits can be challenging as they are not solely dependent on a discrete number of trees, they are predominantly derived from the overall influence of green spaces. Broadly, environments with abundant trees and greenery contribute to stress reduction. Further, being in close proximity to trees has been linked to enhanced moods and increased engagement in physical activity.[219]

Neighborhood Benefits. Urban forestry creates numerous benefits to the society and neighborhood in the area. By enhancing leisure and recreational activities within local urban areas, urban forestry can generate substantial benefits, such as increased leisure time and savings resulting from reduced field consumption associated with traveling to rural areas for recreation.[220]

The strategic planting of trees can also offer significant noise reduction benefits, often reaching a reduction of 50% or more,[221] creating a more pleasant environment for urban dwellers. Additionally, the presence of shade provided by trees facilitates outdoor connectivity for residents, providing comfortable spaces to gather and engage with their surroundings. It is therefore unsurprising that housing and neighborhoods densely populated with trees are valued more; for example, single trees have been shown to increase property values.[222]

Ecological Benefits. Trees in urban areas also provide a habitat for birds and plants that would otherwise be unavailable in those areas. This can lead to important gains in biodiversity, with communities valuing wildlife more in their daily lives.[223]

Appendix H

Non-Carbon Issues and Benefits of Wildfire Mitigation.

Besides reducing carbon, wildfire mitigation has other important benefits. One of the most straightforward benefits is air quality. The effects on air quality from wildfires are clear. In less than two months in 2020, there were thousands of excess deaths attributed to wildfire smoke just in California.[224] The danger from wildfire smoke has led to the need for clean air shelters and cooling centers in Western states.[225] Importantly, the effects of wildfire smoke are not felt equally, and disadvantaged communities suffer the most from smoke.[226] Any reduction in wildfires will improve air quality and benefit the communities most affected by wildfire polluted air.

In addition, wildfires also create risks of flash flooding, debris flows, and disruptions to the water supply. Reforestation after wildfires cannot adequately prevent these effects. Even when reforesting right away, the benefits take years to accrue. Additionally, there is already a reforestation backlog and seeding shortage which grows worse with each fire.[227]

Wildfire mitigation can prevent or reduce these adverse effects. Additionally, many forest species are adapted to periodic natural fires, and mitigation can help maintain tree species diversity, plant diversity, and animal habitats.[228] While thinning and prescribed burn mimic these effects for some species, there is no one size fits all to mimic natural fire disturbances that maximize wildlife diversity.[229] Given the other benefits of these wildfire mitigation tools, however, their effect on habitats is a benefit compared to total fire suppression or the extraordinarily intense stand-replacing fires fueled by climate change, droughts, and long-term fire suppression.

Finally, wildfire mitigation will create jobs, especially in rural areas. No matter the approach taken, increased wildfire mitigation requires more workers in rural areas where unemployment tends to be higher.[230] Altogether, wildfire mitigation can help limit carbon emissions, protect air and water quality, and help with habitats, all while employing workers in regions where unemployment and low wages are most prevalent.

ENDNOTES

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[2] *Global Greenhouse Gas Emissions Data*, U.S. ENV'T PROT. AGENCY, available at https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (last updated 15 Feb. 2023).
[3] William R. L. Anderegg et al., *Future Climate Risks from Stress, Insects and Fire Across US Forests*, 25 ECOLOGY LETTERS 1510-1520 (Anderegg 2022), available at https://onlinelibrary.wiley.com/doi/full/10.1111/ele.14018.
[4] Christopher W. Woodall et al., *The U.S. Forest Carbon Accounting Framework: Stocks and Stock Change, 1990-2016*, U.S. DEP'T OF AGRIC. (2015), available at https://www.fs.usda.gov/research/treesearch/49858 (referenced in David N. Wear, *Tree Planting as Climate Policy?*, RESOURCES FOR THE FUTURE 1-6 (May 2020) at 2, available at https://media.rff.org/documents/IB_20-07_v2.pdf).
[5] For example, the Tongass National Forest in southeast Alaska is part of the largest intact rainforest in the world. National Forest Foundation, available at https://www.nationalforests.org/blog/six-ways-to-experience-the-tongass-national-forest.
[6] David Nowak, *U.S. Urban Forest Statistics, Values, and Projections*, 116 J. OF FORESTRY 164-177 (2018), available at https://doi.org/10.1093/jofore/fvx004 (accessed via U.S Dep't of Agric.).
[7] The term "forests" in this report is used broadly to cover trees that are concentrated in urban areas and on agricultural lands (agroforestry), as well as in traditional dense forests. As discussed in this report, a significant amount of carbon is stored in urban and agroforestry contexts.
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[10] Inflation Reduction Act of 2022 § 21001(a)(1)(B)(iii), 136 Stat. 1818.
[11] *Biden-Harris Administration Announces Plans for New Reforestation, Climate Adaptation, including New Resources from Bipartisan Infrastructure Law*, Release No. 0160.22, U.S. DEP'T OF AGRIC. (25 July 2022), available at https://www.usda.gov/media/press-releases/2022/07/25/biden-harris-administration-announces-plans-reforestation-climate#:~:text=The%20REPLANT%20Act%20directs%20the,every%20year%20to%20do%20so.
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[13] Inflation Reduction Act § 23003 (a).
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[16] *Confronting the Wildfire Crisis*, U.S. DEP'T OF AGRIC, (JAN. 2022), available at https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/Confronting-the-Wildfire-Crisis.pdf
[17] See n.12, supra.
[18] Inflation Reduction Act § 23002(a)(5).
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[20] Wade T. Tinkham et al., *Applications of the United States Forest Inventory and Analysis Dataset: A Review and Future Directions*, CANADIAN J. OF FOREST RESEARCH (19 Sep. 2018), available at https://doi.org/10.1139/cjfr-2018-0196; *Strategic Plan*, U.S. DEP'T OF AGRIC. (14 JULY 2020), available at https://www.fia.fs.usda.gov/library/bus-org-documents/docs/strategic-plan-docs/FIA%20Brochure%20Climate-%208p%20JUL14%20v4d.pdf.
[21] FIA's strengths in plot sampling are also critical to the development of high-quality remote sensing protocols. Cost savings from remote sensing can also enable more investment in phase 3 sampling as well as soil spectroscopy, which are needed to quantify the systems-level carbon sequestration of forests.
[22] The accuracy of these national forest inventory numbers would be improved with integration of remote sensing capabilities.
[23] Darci Paull et al., *High-resolution Land Cover of Kansas (2015)*, U.S. DEP'T OF AGRIC. (2015), available at https://www.fs.usda.gov/rds/archive/catalog/RDS-2017-0025.

[24] Ben Weinstein et al., *Individual Tree-Crown Detection in RGB Imagery Using Semi-Supervised Deep Learning Neural Networks*, 11 REMOTE SENS. 1309 (2019), available at https://doi.org/10.3390/rs11111309.
[25] Compton Tucker et al., *Sub-continental-scale Carbon Stocks of Individual African Drylands*, 615 NATURE DEP'T 80-86 (2023), available at https://doi.org/10.1038/s41586-022-05653-6.
[26] Yifan Yu et al., *Making the US National Forest Inventory Spatially Contiguous and Temporally Consistent*, 17 ENVIRON. RESEARCH LETT. (2022), available at https://doi.org/10.1088/1748-9326/ac6b47.
[27] Ty Wilson, *BIGMAP: FIA's Cloud-based National Scale Modeling, Mapping, and analysis Environment for US forests*, ARCGIS (19 May 2021), available at https://storymaps.arcgis.com/stories/c710684b98f54452804e8960d37905b2.
[28] Andrew J. Lister, et al., *Use of Remote Sensing Data to Improve the Efficiency of National Forest Inventories: A Case Study from the United States National Forest Inventory* (19 Dec. 2020), available at https://www.mdpi.com/1999-4907/11/12/1364.
[29] *Id.*
[30] *Data Progress Needed for Climate Smart Agriculture* (Stanford Law School, 10 April 2022), available at https://law.stanford.edu/publications/data-progress-needed-for-climate-smart-agriculture/
[31] Mobile apps like iNaturalist have already transformed global biodiversity monitoring, and mobile apps like Plantix are being used by farmers around the world to detect and monitor pests. Earthshot labs and Working Trees have been using mobile phones to collect ground data on tree species and diameter at breast height, which are two very important variables that remain a challenge for remote sensing-based methods. Such tools open up the possibility for enabling citizen-science based data collection using mobile apps, and this represents a great opportunity to connect methodological advances that improve the efficiency of tree inventories with improvements in the user experience of landowners and technical assistance providers who participate in data collection programs.
[32] Adam R. Martin et al., *Carbon Fractions in the World's Dead Wood*, 12 NAT. COMM. (2021), available at https://www.nature.com/articles/s41467-021-21149-9.
[33] Kendall DeLyser et al., *Impact of Forest Management and Wood Utilization on Carbon Sequestration and Storage in Pennsylvania and Maryland*, AM. FORESTS (23 Dec. 2022), available at https://www.americanforests.org/wp-content/uploads/2023/02/CBM_PA_report_FINAL.pdf.
[34] *Id*.
[35] The team was able to achieve this through completing the multi-stakeholder process that included: "(1) [Working] with state natural resource agency staff and forestry experts to understand forest management priorities, concerns, and goals… (2) Developing of business-as-usual (BAU) and alternative forest management scenarios—including forest management, natural disturbance, and land-use change—to project future forest carbon trends under various management practices; (3) Modeling scenarios with the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)—parameterized for conditions in Pennsylvania, … [and] (4) Engagement and discussion with state agency staff to explore modeling results, consider implications for forest management programs and policies statewide, and inform state climate action targets."
[36] Recently introduced legislation entitled the "Forest Data Modernization Act of 2023" would take a similar approach. It would charge the Secretary of Agriculture with developing and reporting on improvements to the FIA program, with a particular focus on remote sensing. *See* Forest Data Modernization Act of 2023, S. 1743, available at https://www.congress.gov/bill/118th-congress/senate-bill/1743/text/is?overview=closed&format=xml.
[37] *Forest Inventory and Analysis: Strategic Plan*, U.S. DEP'T OF AGRIC., supra note 20.
[38] For further description of dynamic baselines, *see* Family Forest Carbon Program, *VM0045 Methodology for Improved Forest Management Using Dynamic Matched Baselines from National Forest Inventories, v1.0*, VERRA. (26 Oct. 2022), available at https://verra.org/methodologies/methodology-for-improved-forest-management/.
[39] This is one example of how user-centered sampling design that considers a wide range of new and emerging use cases could benefit climate-smart forestry efforts. Dynamic baselines are not a use case that could have been foreseen 5 years ago, and so we recommend frequent communication and needs assessment with users and researchers on an ongoing basis, and especially when changes or enhancements are being made to sampling protocols. The Forest Service should initiate a collaborative process to identify additional use cases for FIA data and to improve the FIA database to respond to those use cases.
[40] Greenhouse Gas Monitoring & Measurement Interagency Working Group, *The Federal Strategy to Advance an Integrated U.S. Greenhouse Gas Monitoring & Information System*, https://nspires.nasaprs.com/external/viewrepositorydocument/cmdocumentid=923603/solicitationId=%7BDDD1BC85-9276-8FB7-C362-A00E3E427E0D%7D/viewSolicitationDocument=1/GHGMIS%20Draft%20Strategy%20for%20Public%20Comment.pdf.

[41] For example, the database could integrate data from varied sources into a single spatially- and temporally-referenced database from any number of government agencies or other public sources, aggregating across many types of data, e.g., FIA ground samples; Mill surveys; LiDAR; Satellite imagery; NRCS soil mapping; Property ownership and transactions; Wildfire monitoring; Pest outbreak; and Drought and flood monitoring.
[42] Oswald Schmitz et al., *Trophic Rewilding Can Expand Natural Climate Solutions*, 13 NATURE: CLIMATE CHANGE 324-333 (2023), available at https://doi.org/10.1038/s41558-023-01631-6; Xinli Chen et al., *Tree Diversity Increases Decadal Forest Soil Carbon and Nitrogen Accrual*, 618 NATURE 94-101 (2023), available at https://www.nature.com/articles/s41586-023-05941-9.
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[46] K.E. Percy and M. Ferretti, *Air Pollution and Forest Health: Toward New Monitoring Concepts*, 130 ENVIRONMENTAL POLLUTION 113-126 (July 2004) available at https://www.sciencedirect.com/science/article/pii/S0269749103004214?casa_token=MQ4AK0jkvuUAAAAA:qSWX1rPzJ-3AbLoArvSLOzG6PlmmpFF1wKHHQWTwbs_h-CiBG6p9jyKOje_VIrqww-upS0lsRgQ
[47] Melissa Chapman et al., *Large Climate Mitigation Potential from Adding Trees to Agricultural Lands*, GLOBAL CHANGE BIOLOGY (2020), available at https://doi:10.1111/gcb.15121, s*ee also* Bronson Griscom et al., *Natural. Climate Solutions*, PNAS (2017), available at https://www.pnas.org/doi/pdf/10.1073/pnas.1710465114; Susan C. Cook-Patton et al., *Lower Cost and More Feasible Options to Restore Forest Cover in the Contiguous United States for Climate Mitigation*, ONE EARTH (18 Dec. 2020), available at https://doi.org/10.1016/j.oneear.2020.11.013.
[48] *Id.*
[49] Matthew M. Smith et al., *Agroforestry Extent in the United States: A Review of National Datasets and Inventory Efforts*, 12 AGRICULTURE (2022) available at https://www.mdpi.com/2077-0472/12/5/726.
[50] *USDA National Agroforestry Center*, U.S. DEP'T OF AGRIC., available at https://www.fs.usda.gov/nac/.
[51] R. D. Lasco, et al., *Climate Risk Adaptation by Smallholder Farmers: The Roles of Trees and Agroforestry*, Current Opinion in 6 ENVIRONMENTAL SUSTAINABILITY 83–88 (2014), available at https://doi.org/10.1016/j.cosust.2013.11.013.
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[53] Susan C. Cook-Patton et al., *Lower Cost And More Feasible Options To Restore Forest Cover In The Contiguous United States For Climate Mitigation,* supra note 47.
[54] Miguel A. Alteri et al, *The adaptation and mitigation potential of traditional agriculture in a changing climate* (13 Sept. 2013), available at https://link.springer.com/article/10.1007/s10584-013-0909-y (citing Mutuo et al., 2005).
[55] *Id* (citing Montagnini and Nair, 2004).
[56] *See* n.30, supra.
[57] M.M. Smith et al., *Silvopasture in the USA: A Systematic Review of Natural Resource Professional and Producer Reported Benefits, Challenges, and Management Activities*. AGRIC. ECO. ENVIRON. 326 (2022), available at https://doi.org/10.1016/j.agee.2021.107818.
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[63] Personal conversation between Fred Iutzi, Director of Research & Commercialization, Savanna Institute and Katie Vogelheim (June 9, 2023).

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[65] *Energy Earthshots Initiative*, U.S. DEP'T OF ENERGY, available at https://www.Energy.gov/policy/energy-earthshots-initiative.
[66] *Ramping up Reforestation in the United States: A Guide for Policymakers*, AMERICAN FORESTS 1-35 (Mar. 2021), available at https://www.americanforests.org/wp-content/uploads/2021/10/Ramping-Up-Reforestation_FINAL.pdf.
[67] *Id*.
[68] *U.S. Department of the Interior and U.S. Department of Agriculture: Reforestation Goals and Assessments, and a Climate-Informed Plan to Increase Federal Seed and Nursery Capacity As Directed by Executive Order 14072,* (Apr. 2023), available at https://www.usda.gov/sites/default/files/documents/joint-reforestation-report.pdf.
[69] See the graph above, from REFORESTATION HUB, available at https://www.reforestationhub.org/about.
[70] See note 68, supra.
[71] USDA Forest Service Reforestation Strategy (July 2022), available at https://www.usda.gov/sites/default/files/documents/reforestation-strategy.pdf.
[72] See note 68, above.
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[74] For example, the Nature Conservancy has estimated that reforestation potentially could capture up to 535 million tons of carbon dioxide per year, or more than a quarter of U.S. annual emissions from cars and light-duty trucks. See https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/reforesting-united-states-susan-cook-patton/
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