



# Carbon Storage, Credit Markets, and Forests

What do we have and what do we need?

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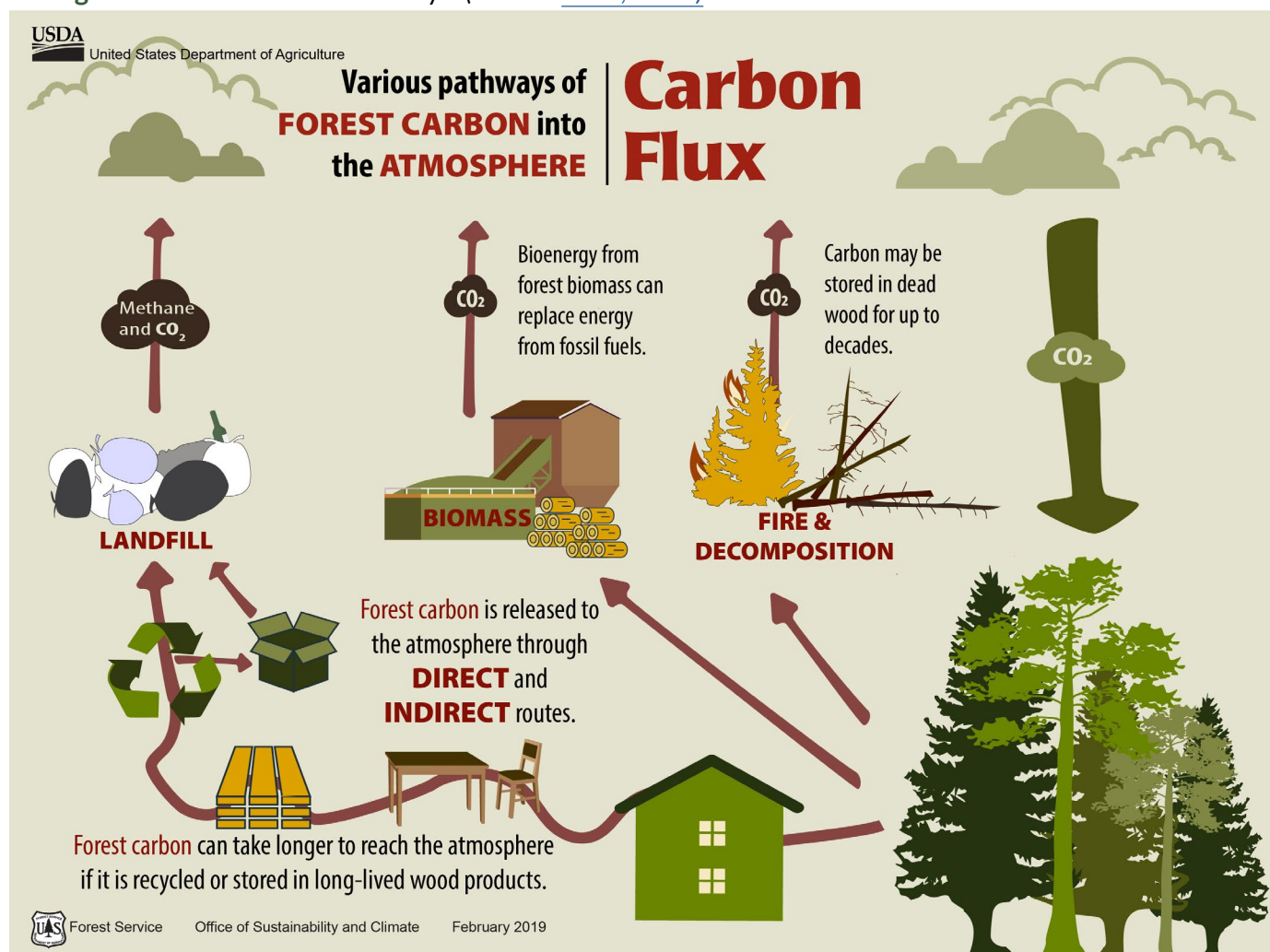
## Introduction

Over the years, Dovetail Partners has reported on carbon storage in forests and many dimensions of the science of sequestration. Our reports have examined carbon in trees and forest products, understanding the carbon cycle, and managing forests for climate change mitigation.<sup>1</sup> This report focuses on carbon credits derived from the forest sector; associated markets, their status, and recent developments. It focuses on US developments while considering the global context. With the increased attention given to the monetization of carbon benefits provided by forests, it is worth examining recent developments and what is on the horizon for forest carbon within the voluntary and regulatory markets.

## Forest Carbon

Forest carbon offsets, crediting systems, and the associated markets, are rooted in the tree's ability to store carbon. Through photosynthesis, trees and other vegetation in the forest convert carbon dioxide from the atmosphere into stored carbon. The chemical composition of wood, whether the wood is in the form of a tree or in the form of a harvested wood product, is about one-half carbon (measured by dry weight). Carbon in the forest is also stored in forest soils and other components of the ecosystem.<sup>2</sup> Carbon accumulates as trees and vegetation expand in size and volume and as carbon is incorporated into the soils. This growth constitutes the above and below ground biomass – main tree stem, branches, bark, and roots. Carbon dioxide is released (emitted) at varying rates from the forest through decomposition of dead and dying trees and other vegetation or from disturbance events such as wildfire and other changes in forest growth and mortality balances. Carbon is removed from the forest through harvesting of both timber and non-timber forest products, and some of this carbon is stored in wood and paper products, including within the built environment and other uses which can span many decades (Figure 1).

Figure 1. Forest Carbon Pathways (Source: [USFS, 2019](#))



## Forest Carbon Pools and Mitigation Options

The United Nations Intergovernmental Panel on Climate Change (IPCC) identifies the carbon stored in forest ecosystems within five pools, with an additional two pools to account for forest-derived products.

The five ecosystem pools are:

1. **Aboveground biomass:** All living biomass above the soil such as stem, stump, branches, bark, seeds, and foliage. This includes the live understory.
2. **Belowground biomass:** All living biomass below the soil surface, such as coarse living roots >2 mm in diameter.
3. **Dead wood:** All non-living woody biomass such as standing and lying dead wood, does not include litter or deadwood found in the soil.
4. **Litter:** This category contains all litter, fomic, and humic layers, as well as non-living biomass with a diameter less than 7.5 centimeters at transect intersection laying on the ground.
5. **Soil organic carbon:** All organic material down to 1 meter below the surface, excluding the below ground pool.

The additional pools that account for forest-derived products (non-ecosystem forest carbon) are:

1. **Harvested wood products (HWP) in use:** This accounts for all currently utilized wood products, such as furniture, lumber, paper, wood pellets, fuelwood, mass timber products, etc.
2. **Harvested wood products in waste disposal sites:** This pool accounts for wood products currently in solid waste disposal sites such as landfills.

Because of the basic role of trees, forests, and harvested wood products in the biogenic carbon cycle, there has been interest in applying forest management practices and the expanded use of forest products to meet climate mitigation goals.

The IPCC has identified the following activities within “the forest sector mitigation portfolio”:

- reducing deforestation,
- forest management,
- afforestation/reforestation,
- agroforestry,
- harvested wood products, and
- forest products/bioenergy to replace fossil fuel use

<sup>1</sup> Dovetail's reports are available at <http://www.dovetailinc.org> and reports addressing carbon sequestration and mitigation include: [A Forest Carbon Future: Recognizing Carbon-Related Benefits Of Managed Forests](#), [Building With Wood: Proactive Climate Protection](#), [Recognition Of Carbon Storage In Harvested Wood Products: A Post-Copenhagen Update](#).

<sup>2</sup> For additional background on forest carbon, see Dovetail Reports: [Carbon 101: Understanding The Carbon Cycle And The Forest Carbon Debate](#) and [Managing Forests For Carbon Mitigation](#)

<sup>3</sup> IPCC, 2019. [Climate Change and Land](#): an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. For further background on the IPCC, also see: [Understanding the Role and Findings of the Intergovernmental Panel on Climate Change \(IPCC\)](#)

<sup>4</sup> Collectively, the carbon associated with the oceans and land is termed “biogenic carbon”. Collectively, carbon associated with the burning of fossil fuels is termed “fossil carbon.” The biogenic carbon cycle has been operating for millions of years. The fossil carbon cycle developed only in the past 100 years, and substantially over only the past six decades. For further discussion, see: [Carbon 101: Understanding The Carbon Cycle And The Forest Carbon Debate](#).

<sup>5</sup> Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsidig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, X. Zhang, 2007: Forestry. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. [ar4-wg3-chapter9-1.pdf \(ipcc.ch\)](#)

Forests and forest products may be one of the most important climate change solutions, in part because of what they already do for the climate and because of the potential to enhance their carbon storage capacity through relatively low cost and low-tech actions. Globally, existing forests absorb approximately 2.6 billion tons of carbon dioxide annually, equivalent to one-third of the CO<sub>2</sub> released from burning fossil fuels each year. It is estimated that more than 850 million acres (350 million hectares) around the world could benefit from forest restoration activities, thereby sequestering up to 1.7 billion metric tons of additional carbon dioxide annually.<sup>6</sup> Within the US, the existing benefits and potential of forests are similarly significant. Forestlands, including actively managed timber producing lands, in the US are currently storing approximately 150 billion tons of carbon dioxide and sequestering an additional 1.5 billion tons annually, which is greater than the annual emissions from passenger vehicles in the country (1 billion tons).<sup>7</sup> Millions of acres that could benefit from forest restoration activities have also been identified within the US and have the potential to provide enhanced carbon storage.<sup>8</sup>

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Forest ecosystems have long been recognized for their carbon storing and sequestering functions. Reforestation offsets and other forest carbon credits were included in the earliest days of the Chicago Climate Exchange (CCX).<sup>9</sup> The concept of improved forest management (IFM)<sup>10</sup> has also been incorporated into carbon protocols, including the basic approach of establishing a baseline or “business as usual” scenario for a given forest area and then modifying management practices (alternative treatments) to improve upon the carbon capture, thereby gaining credits for the additional carbon storage (or emission reduction) associated with that change.<sup>11</sup> Carbon offsets are available only

## Offsets vs. Credits

The terms offsets and credits are often used interchangeably, although they have slightly different meanings. A carbon offset broadly refers to a reduction in greenhouse gas (GHG) emissions – or an increase in carbon storage - that is used to compensate for emissions. A carbon credit is a transferrable instrument recognized via a carbon market to represent an emission reduction of one metric ton of CO<sub>2</sub>, or an equivalent amount of other GHGs. The purchaser of a credit can “retire” it to claim the underlying reduction towards their own GHG reduction goals. A “carbon offset” is shorthand for GHG emission reductions or removals that compensate for CO<sub>2</sub> emissions that occur elsewhere. Additionally, the purchasers of carbon are more likely to refer to them as offsets (as viewed from their perspective), and the producers of carbon storage benefits are more likely to refer to them as credits (reflective of their role in the market).

For definitions of additional terms, see: [Forest Carbon Primer \(congress.gov\)](#). Also see the [IPCC Glossary and Carbon Offset Guide](#)

<sup>6</sup>IUCN, Forests and Climate Change, Issue Brief. February 2021. <https://www.iucn.org/resources/issues-briefs/forests-and-climate-change>

<sup>7</sup>Forest Carbon Data Viz, 2021

<sup>8</sup>For additional information, see: [Large-scale forest restoration stabilizes carbon under climate change in Southwest United States, USDA Forest Services Restoration, Regional Baseline Carbon Reports \(USFS\)](#)

<sup>9</sup>The Chicago Climate Exchange (CCX) was a voluntary greenhouse gas reduction and trading system for emission sources and offset projects operating from 2003-2010. [Chicago Climate Exchange - Wikipedia](#); also see: <http://ww2.arb.ca.gov/sites/default/files/classic/research/seminars/ccx/ccx.pdf>

<sup>10</sup>Forest carbon offset projects based on IFM involve land management activities that increase or at a minimum maintain the current level of carbon stocking. [\(An Introduction to Forest Carbon Offset Markets | NC State Extension Publications \(ncsu.edu\)\)](#)

<sup>11</sup>For an illustration of forest carbon credit calculations using a baseline vs. alternative treatment analysis and the 2009 requirements of the CCX and Voluntary Carbon Standard (VCS), see: Minnesota North Woods Carbon Credit Partnership, Project Report, available at: <https://dovetailinc.org/upload/tmp/1590695521.pdf>

when additionality is involved and simply capturing carbon in a business as usual scenario is not eligible for carbon offset credits. Carbon offset protocols include mechanisms for accounting for carbon storage in harvested wood products (HWP), as referenced in the IPCC identified pools.<sup>12</sup> The IPCC provides guidance on how to estimate and report the contribution of HWPs to annual CO<sub>2</sub> emissions/ removals.<sup>13</sup>

## Recent Developments, post-2010

When the CCX ceased trading in 2010 due in part to the lack of domestic policy development it was viewed as a low point in the development of carbon markets, especially within the United States.<sup>14</sup> At its peak, the CCX included more than 400 public and private sector members and a trading volume of 680 million metric tons of CO<sub>2</sub>. Post-2010, there has been a reemergence of interest in carbon offsets as a mitigation measure for climate change. The numerous net-zero<sup>15</sup> and emission reduction commitments that have been made in recent years (i.e., by more than 1500 companies,<sup>16</sup> including about 8% of the world’s largest companies represented by the Global Fortune 500<sup>17</sup>) indicate that the potential market for carbon offsets by 2030 could be up to 5 billion metric tons of carbon dioxide equivalent (CO<sub>2</sub>e), an amount that is comparable to the total energy-related carbon dioxide emissions of the US in 2019.<sup>18</sup>

An emerging area of focus in responding to the growing demand for carbon offset credits is the use of Natural Climate Solutions (NCS), which include conservation, restoration, and/or improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across forests, wetlands, grasslands, and agricultural lands.<sup>19,20</sup> NCS efforts include actions to protect, sustainably manage, and restore natural and modified ecosystems in ways that mitigate climate change. These actions include a strong forest ecosystem component and have the potential to provide over one-third of the climate mitigation that is needed by 2030.<sup>20</sup> Estimates are that up to two-thirds of the carbon offset market could be served by NCS, with an annual investment impact of tens of billions of dollars.<sup>21</sup>

<sup>12</sup>For example, see Chapter 5 of: [Compliance Offset Protocol US Forest Projects \(June 25, 2015\) \(ca.gov\)](#)

<sup>13</sup>IPCC, 2006. Chapter 12, Harvested Wood Products. [https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4\\_Volume4/V4\\_12\\_Ch12\\_HWP.pdf](https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf). For additional discussion, see: [Carbon Storage and Climate Change Mitigation Potential of Harvested Wood Products](#), April 2021, Food and Agricultural Organization of the United Nations Forest Products and Statistics Team, Background Paper prepared for the 61st Session of the FAO Advisory Committee on Sustainable Forest-based Industries

<sup>14</sup>CCX members anticipated strong federal action on regulating greenhouse gases, but it did not materialize and the value of credits in a non-regulatory market was eroded. [\(The Collapse of the CCX Carbon Emissions Contract, Aug. 17, 2009\)](#)

<sup>15</sup>Net zero refers to a state in which the greenhouse gases going into the atmosphere are balanced by removal out of the atmosphere.

<https://netzeroclimate.org/>

<sup>16</sup>[Science Based Targets Initiative \(2021\)](#)

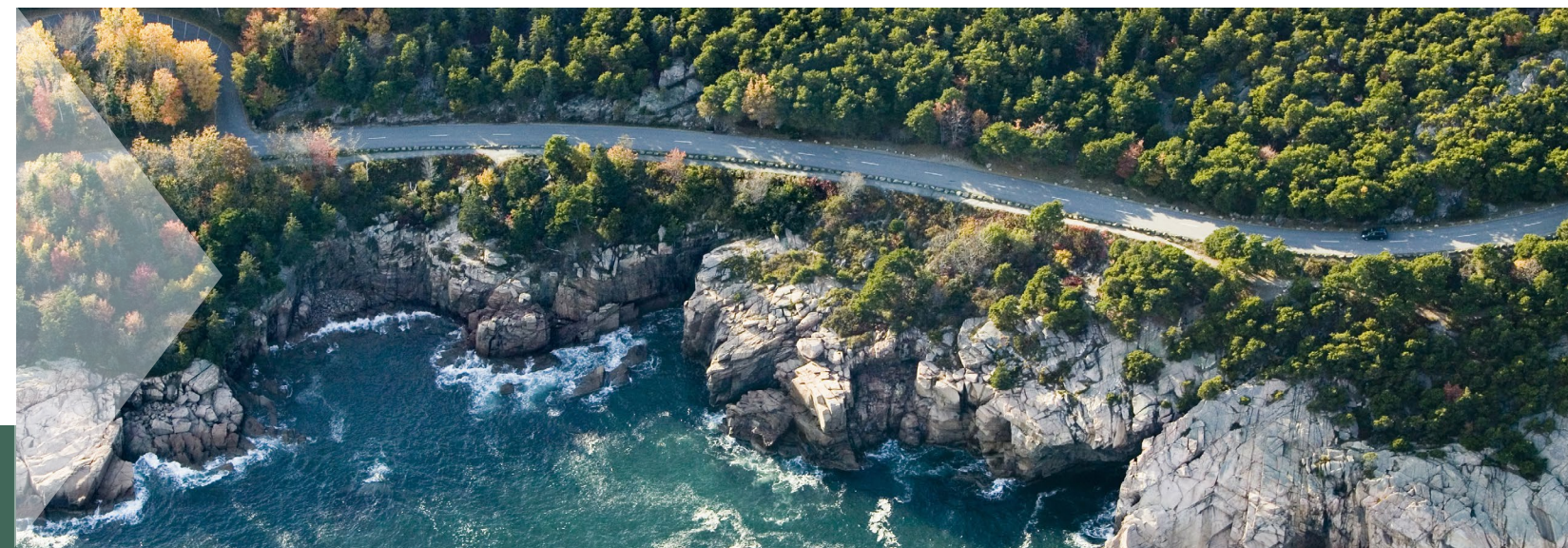
<sup>17</sup>[How business can bridge the gap and achieve net zero \(PWC, 3/1/21\).](#)

<sup>18</sup>A gigaton is a billion metric tons, and the U.S. Energy Information Administration ([US EIA](#)) estimates that in 2019, the US emitted 5.1 billion metric tons of energy-related carbon dioxide while the global emissions of energy-related carbon dioxide totaled 33.1 billion metric tons.

<sup>19</sup>Natural Climate Solutions, 2017. <https://www.pnas.org/content/114/44/11645>

<sup>20</sup>Also referred to as [Nature Based Solutions](#) (NbS) defined by the International Union for the Conservation of Nature (IUCN) in 2016 as “actions to protect, sustainably manage, and restore natural or modified ecosystems” to help mitigate climate change and/or help people and nature adapt to climate change.

<sup>21</sup>[Corporate Financing of Nature Based Solutions: What Next? April 5, 2021. WRI.](#)



The recent renewed interest in carbon offsets is reflected in both regulatory and voluntary markets, with innovation particularly pronounced in the voluntary markets in part because there is greater flexibility and opportunity to innovate.<sup>22</sup>

### Voluntary & Compliance Carbon Markets

**Voluntary Carbon Market:** The voluntary carbon market enables the voluntary purchase of carbon credits to offset emissions. The largest category of buyers is private firms that purchase carbon credits for resale or investment and to meet voluntary “net zero” or carbon emission reduction commitments.

**Compliance Carbon Market:** The compliance market, also known as the regulatory market, enables the purchase of carbon offset credits to comply with caps on the amount of greenhouse gases that regulated industries are allowed to emit. The EU Emissions Trading Scheme and the California cap and trade program are leading international and domestic examples.

For additional information: [Voluntary Carbon Market - Overview, Participants, and Advantages \(corporatefinanceinstitute.com\)](https://www.corporatefinanceinstitute.com)

However, as shown in Table 1, there is a wide gap between existing carbon offset capability and projected demand, with current voluntary markets only providing 8-13% of what the domestic market may demand within the decade. In 2016, the voluntary market provided offsets for 63.4 million metric tons of CO<sub>2</sub> at a cost of \$191.3 million.<sup>23</sup> <sup>24</sup> In comparison, regulatory markets were valued at \$142 billion in 2010.<sup>25</sup> Also, as shown in Table 1, the current estimated payments to landowners are in the range of \$20-\$215/acre/year and at those levels traditional forest product markets as well as cost-share programs remain economically important as these carbon related revenues are unlikely to cover the costs of landownership and the costs of management activities such as wildfire risk mitigation, tree planting, invasive species removals, and other actions to enhance ecosystem resilience and carbon storage.<sup>26,27</sup>



<sup>22</sup>One measure of flexibility is the period of commitment associated with each market. Voluntary carbon markets typically offer a 40-year commitment with new models emerging with shorter enrollment periods, as little as one year. Regulatory markets often require 100 years. See Appendix A for a comparison of some programs.

<sup>23</sup>The 63.4 million metric tons of CO<sub>2</sub> offset in 2016 represented less than a quarter of 1% of global annual carbon emissions. [As climate change looms, a booming market for carbon offsets - Marketplace](#). D. Merino. Sep 13, 2019.

<sup>24</sup>The annual market report by Forest Trends estimated a transaction volume of at least 104 million metric tons of CO<sub>2</sub> on the voluntary market in 2019, representing an increase of 6 percent over 2018. [State of the Voluntary Common Markets 2020](#) also see: [Global Carbon Hub for Data and Insights on Carbon Markets and Voluntary Offsets - Ecosystem Marketplace](#)

<sup>25</sup>[Rehabilitation forestry and carbon market access on high-graded northern hardwood forests \(2014\)](#)

<sup>26</sup>For further discussion of interactions between carbon offset pricing and forest management, see: [Break-Even Analysis for Forest Carbon Contracts](#) and [Forest Carbon 201: Land Use Effects of Wood Product Markets](#) Examples of conservation activities and federal cost-share rates are available at [2021 State Payment Schedules | NRCS \(usda.gov\)](#) and for a discussion of carbon pricing, see: [An inside look at pricing in the forest carbon market](#), March 2, 2021.

<sup>27</sup>It is estimated that a \$160/tonne carbon price is needed by 2030 to reach net-zero goals. [600% Gain in Carbon Prices Vital to Rein in Global Warming - Bloomberg](#)

**Table 1. Carbon Offset Supply and Demand**

Market	Summary Data	Full Description
Voluntary Market Supply (2016, 2019) <sup>23,24</sup>	104 million MtCO <sub>2</sub> e	63.4 to 104 million metric tons of CO <sub>2</sub> equivalent (MtCO <sub>2</sub> e)
Voluntary Market Price (2018) <sup>28</sup>	\$3/ MtCO <sub>2</sub> e	\$0.1/MtCO <sub>2</sub> e to \$70/MtCO <sub>2</sub> e (average price of \$3/MtCO <sub>2</sub> e)
Estimated payments to landowners <sup>29</sup>		Payments ranging from \$100-\$214 per acre over a 10 to 20 year contract; or from \$20-\$100 per acre per year
Regulatory Market Supply (2014, California cap-and-trade program) <sup>30</sup>	144 million MtCO <sub>2</sub> e	144 million offsets* total; approx. 12 million annually
Regulatory Market Prices (2020, California cap-and-trade program) <sup>31</sup>	\$17.42/ MtCO <sub>2</sub> e	\$17.39 to \$17.42/MtCO <sub>2</sub> e
Market Demand, Global (2030) <sup>32</sup>	Up to 5 billion MtCO <sub>2</sub> e	1 to 5 billion metric tons of carbon dioxide equivalent (CO <sub>2</sub> e)
Market Demand, USA (2030)*	Up to 0.75 billion MtCO <sub>2</sub> e	Up to 750 million metric tons of CO <sub>2</sub> e (estimated at 15% of global demand)

\* Author estimate

The supply and demand conditions in carbon markets have been identified as central to the acceptance of offset trading and for the assurance of real and equitable climate benefits. The World Resources Institute (WRI)<sup>32</sup> has stated:

Ensuring a positive outcome requires observing two overarching principles concerning the demand and supply of credits.

- 1. Demand for Credits:** Carbon credits must not provide a corporation with an incentive or excuse to delay emission reductions within its own operations and value chain. Offsets must enhance, not dilute, the pace of emissions reduction.
- 2. Supply of Credits:** Investments must be ecologically and socially sustainable and must meet a set of standards ensuring integrity – in terms of Paris-aligned levels of ambition, additionality, permanence, and avoidance of leakage and double counting.

<sup>28</sup>[An Introduction to Forest Carbon Offset Markets | NC State Extension Publications \(ncsu.edu\)](#)

<sup>29</sup>New Carbon Credit Opportunities, 2021. <https://www.engaginglandowners.org/node/3450>

<sup>30</sup>[Assessing the Market for California Carbon Offsets \(2014\)](#), Carbon Americas Group

<sup>31</sup>[December 2020 Calif. carbon allowance price extends gains into year's end | S&P Global Market Intelligence \(spglobal.com\)](#)

<sup>32</sup>[Corporate Financing of Nature Based Solutions: What Next? April 5, 2021. WRI.](#)

<sup>33</sup>For further discussion, see: [What Makes a High-Quality Carbon Offset?](#) Also worth noting that similar quality assurance debates exist in other emerging environmental markets with parallel development of applicable principles. For example, see: [The Wild West of plastic credits and offsets | Greenbiz](#)

<sup>34</sup>For further discussion, see [Scope 1, 2, and 3 Inventory Guidance](#), EPA Center for Corporate Climate Leadership, 2021.

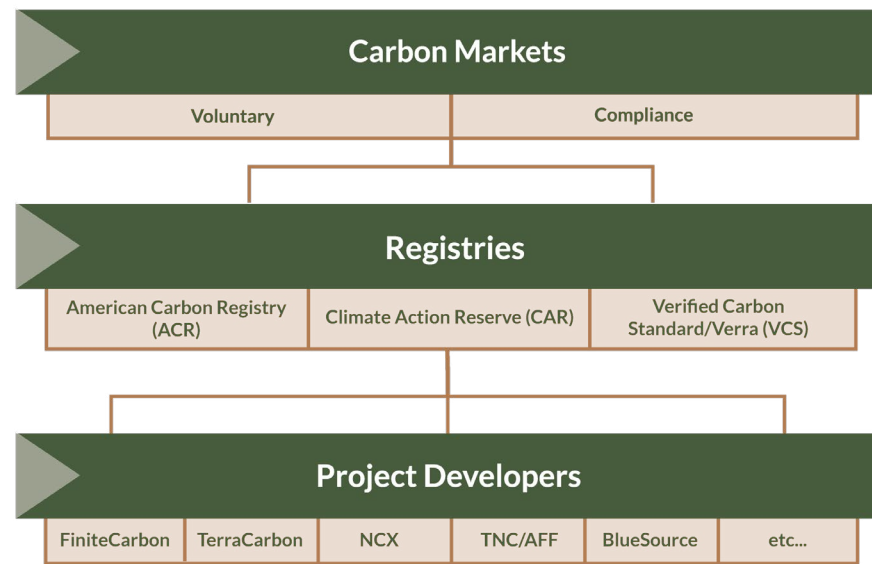


# The Carbon Marketplace

The following figure illustrates the structure of the carbon marketplace (Figure 2). Beginning at the top are the two broad categories of voluntary and compliance markets, as described in Box 1. These two types of markets and represent differences in defined roles for public and private sector interests. The middle layer shows the registries, which are the platforms for listing qualified projects and eligible credits for sale. The major registries shown in Figure 2 list credits for both voluntary and compliance markets. The third layer is the project developer role. These are the independent organizations and consulting firms that engage with forest owners and land managers to evaluate the feasibility of projects and conduct the necessary analysis and verification to confirm that a project is eligible to be listed in a registry (by conforming to the registries' criteria) so the resulting credits can be offered for sale. (Only an illustrative sample of project developers and their respective programs is shown in Figure 2. Also see Appendix A for a Comparison of Forest Carbon Programs available to forest owners in the US.)



Figure 2. Carbon Market Structures



If Figure 2 is viewed from the bottom up, it can be understood as representing the entities that land managers are most likely to encounter as they explore carbon market opportunities. The project developers are the organizations that are generally reaching out to landowners to offer services and directly contract with landowners or sign them up.<sup>35</sup> Landowners can request proposals from multiple project developers to understand alternatives and compare service offerings. When a landowner engages with a project developer, one of the steps in the process will be determining which registry to pursue. Many project developers offer services for multiple registries because the choice of a registry will influence the project design and the protocol (i.e., methodologies) used to calculate the eligible credits.<sup>36</sup> Project developers can also be engaged to develop new methodologies for specific registries, which is a more costly and time consuming process than utilizing an existing protocol.<sup>37</sup> Lastly, in working with a project developer, the landowner will need to determine which carbon market (voluntary or compliance) they wish to engage in, which influences the project design as well as the potential value of the resulting credits.

<sup>35</sup>For an article with insights from multiple project developers, see: [An inside look at pricing in the forest carbon market | Greenbiz](#)

<sup>36</sup>For example, see the Climate Action Reserve (CAR) - [project map](#); a summary of the impact of CAR's 22 protocols, and the [ACR, forest offset standard](#).

<sup>37</sup>For an example of the process for developing a new methodology, see: [Develop a Methodology - Verra](#)

# Natural Climate Solutions – What we have

Recent analysis has shown that if natural climate solutions, including forest carbon offset credits, are going to meaningfully influence climate change scenarios, they need to occur at a scale of millions of acres and billions of dollars of investment annually.<sup>38</sup> The World Economic Forum estimates that the voluntary carbon market would need to grow by more than 15-fold by 2030 to support the recommended climate mitigation pathways.<sup>39,40</sup> To limit global warming to 1.5°C above pre-industrial levels, the world must halve CO2 emissions by 2030 and reach net-zero CO2 emissions by 2050 (through emissions reductions and offsets).<sup>41</sup>

The challenge of offset credit supply is illustrated in Table 2 which focuses on the capacity of US forests to contribute carbon mitigation benefits. As shown in lines 1, 2, and 3, the forests of the US are immense (766 million acres) and already store and sequester carbon at a significant scale and rate. Across the US, forests, urban trees, and harvested wood products remove 14% of all CO2 emissions and store the equivalent of 33 years of all CO2 emissions produced across the US.<sup>42</sup>

Also noteworthy within Table 2 are lines 4 and 5 showing that forests in the US are expected to have declining sequestration capacity in the future based upon the continuation of current trends related to climate change and land use. These declines are expected to occur as:

- average forest age continues to increase (older forests can store more carbon but they sequester additional carbon at a slower rate),
- disturbance events occur and potentially increase (wildfire, insect and disease, and
- other natural disasters), and
- land-use changes continue (e.g., agricultural, municipal, and industrial development).<sup>43</sup>

Furthermore, as shown in line 6, even with a scenario of policy action to reduce the land conversion impacts of development, incentives for tree planting, and reduced wildfire related emissions, it is difficult to maintain current US forest carbon sequestration rates through 2050. Bottom line, as shown in lines 7, 8 and 9, when looking at forest carbon metrics from a domestic supply and demand perspective, the total area of forest carbon offset activity in the US likely needs to expand nearly 10-fold from existing levels to meet protected domestic offset demand by the end of this decade and to meaningfully contribute to a national net-zero goal by 2050. The urgency to invest in forest health in the US is immediate and supported by many factors, including climate change mitigation.

<sup>38</sup>[The Economics of US Forests as a Natural Climate Solution](#) April 29, 2021, Ohio State University.

<sup>39</sup>[How to scale effective voluntary carbon markets in 6 steps | World Economic Forum \(weforum.org\)](#)

<sup>40</sup>The 1.5°C emission pathways are defined as those that, given current knowledge of the climate response, provide a one- in-two to two-in-three chance of warming either remaining below 1.5°C or returning to 1.5°C by around 2100 following an overshoot. [Global Warming of 1.5 °C – \(ipcc.ch\)](#). Also see the most recent [IPCC report](#) (6th Assessment Report, Working Group 1, 9 Aug 2021) and associated [discussion of the 5 scenarios](#).

<sup>41</sup>Science Based Targets, Net-Zero, 2021 <https://sciencebasedtargets.org/net-zero>

<sup>42</sup>[Carbon Fact Sheet \(forestresources.org\)](#)

<sup>43</sup>For discussion of these trends globally, see: [Deforestation Linked to 7 Agricultural Commodities \(WRI 2021\)](#) and for future forest projections for the US, see: [The Next 100 Years of Forests in the U.S.](#)

**Table 2. Forest Carbon Metrics , USA**

Forest Carbon Metric		Measured Scale/Impact
1	Forestland area (50 states) <sup>1</sup>	766 million acres
2	Forest carbon storage (50 states) <sup>1</sup>	149,560 million MtCO <sub>2</sub> e
3	Forest carbon sequestration (50 states) <sup>1</sup>	1,068 million MtCO <sub>2</sub> e/year
4	Forest carbon sequestration, annual (2015) (48 states) <sup>2</sup>	480 million MtCO <sub>2</sub> e /year
5	Forest carbon sequestration, projected baseline (2050) (48 states) <sup>3</sup>	323 million MtCO <sub>2</sub> e /year*
6	Forest carbon sequestration, projected policy scenarios (2050) (48 states) <sup>4</sup>	469 to 480 million MtCO <sub>2</sub> e /year
7	Current area of forest carbon offset projects, (2021)**	< 8 million acres
8	Area of forest carbon offset projects needed to meet estimated market demand, (2030)***	75 million acres
9	Area of forest carbon offset projects needed to meet 50% of total US emission****	334 million acres

<sup>1</sup> Forest Carbon Data Viz, 2021

<sup>2</sup> Estimating the Present Value of Carbon Sequestration in U.S. Forests, 2015–2050, for Evaluating Federal Climate Change Mitigation Policies (fs.fed.us)

<sup>3</sup> The baseline scenario anticipates the elimination of net gains in forest area by 2025, followed by a slight decline in forest area through 2050, and represents assumptions developed for the 2016 U.S. biennial report (U.S. Department of Agriculture. 2016. USDA Integrated Projections for Agriculture and Forest Sector Land Use, Land- Use Change, and GHG Emissions and Removals: 2015 to 2060. Office of the Chief Economist, USDA, Washington, DC. Available at [http://www.usda.gov/oce/climate\\_change/mitigation.html](http://www.usda.gov/oce/climate_change/mitigation.html)) (see: Estimating the Present Value of Carbon Sequestration in U.S. Forests, 2015–2050, for Evaluating Federal Climate Change Mitigation Policies (fs.fed.us))

<sup>4</sup> Three policy scenarios: (1) a land-use policy to reduce deforestation from development (no net forest area loss beginning in 2025); (2) an afforestation policy targeting rural landowners in the eastern United States and a reforestation policy targeting understocked federal forest lands in the western United States (12.1 million hectares of reforestation between 2015 and 2020); and (3) a policy reducing stand-replacing fire events by 10%. (see: Estimating the Present Value of Carbon Sequestration in U.S. Forests, 2015–2050, for Evaluating Federal Climate Change Mitigation Policies (fs.fed.us))

\*Projected annual carbon sequestration under a baseline scenario shows declines compared to 2015 due to forest aging, forest disturbance, and land-use change.

\*\*Author estimate based upon publicly available information

\*\*\*Author estimate based upon estimated demand of 0.75 billion MtCO<sub>2</sub>e (see Table 1) and an estimated sequestration rate of 10 MtCO<sub>2</sub>e per acre per year.

\*\*\*\* Author estimate based upon US emissions in 2018 (6,679 million MtCO<sub>2</sub>e) and an estimated sequestration rate of 10 MtCO<sub>2</sub>e per acre per year.<sup>44</sup>

<sup>44</sup> IPCC estimate for afforested areas of 5-10 tons of carbon sequestered per ha per year (2-4 tons of carbon per acre per year). The carbon dioxide equivalent of 1 ton of carbon is 3.67 tons resulting in an estimate of 7 - 15 MtCO<sub>2</sub>e sequestered per acre per year.



## Natural Climate Solutions – What we need

Forests are ever-changing ecosystems, and as shown in the data, significant investment in policy actions, forest care and stewardship, and landowner engagement will be necessary, just to keep the climate mitigation capacities that currently exist in US forests, much less to expand them.

In general, the renewed interest in carbon offsetting through natural climate solutions is leading to development of new protocols for defining eligible credits,<sup>45</sup> expansion of the use of technology for measuring and monitoring offsets,<sup>46</sup> and the potential for greater financial investment from corporations and private sector interests,<sup>47</sup> as well as risk reducing guarantees and actions from governments.<sup>48</sup> These trends are encouraging and with the recent scaling up of interest, innovation, and investment, it appears that carbon offsets, and forest carbon credits specifically, might be able to reach a meaningful level of impact as a climate change mitigation strategy. For this potential to be realized, the forest sector and its many partners will play a critical role. In this regard, there are three fundamental principles:

- Embrace Complexity
- Commit to Solving the Energy Dilemma
- Learn from Past Success

**Embrace Complexity  
- Let's bring all of our  
solutions and engage  
all of our allies!**

Climate change has the elements of a “wicked problem.”<sup>49</sup> No single proposed IPCC carbon storage strategy is sufficient to sequester enough carbon to prevent exceeding a 1.5°C threshold individually; a suite of strategies is needed to meet that goal (See Appendix B for the list of *Seven Carbon Capture and Storage Technologies named by the IPCC.*). In this context, it needs to be recognized that climate change stems from multiple causes, with multiple solutions,<sup>50</sup> but with no clear end point. There will also be many varying and competing viewpoints related to the urgency of climate change and its consequences.<sup>51</sup> This uncertainty creates a challenging environment for policymakers - who prefer to know the outcomes and impacts of proposed regulations when spending public money to support public good - and for private sector investors - who want some level of risk mitigation or a guarantee to align with their revenue generating objectives.

<sup>45</sup>For example, see: [FFCP Gets Go-Ahead on New Methodology Concept \(forestfoundation.org\)](https://www.forestfoundation.org/en/article/2021/04/ffcp-gets-go-ahead-on-new-methodology-concept)

<sup>46</sup>For example, see: [NCX](https://www.nature.com/articles/s41560-021-00888-8) and [Forest Carbon Works](https://www.forestcarbonworks.com/)

<sup>47</sup>For example, see: [BP invests in forest carbon offsets leader Finite Resources](https://www.bpcorp.com/newsroom/bp-invests-in-forest-carbon-offsets-leader-finite-resources), [Microsoft will be carbon negative by 2030](https://www.apple.com/planet/newsroom/2021/03/apple-and-partners-launch-first-ever-200-million-restore-fund/), [Apple and partners launch first-ever \\$200 million Restore Fund](https://www.amazon.com/press-releases/amazon-commits-10-million-to-restore-and-conserve-4-million-acres-of-forest-in-the-appalachians-and-other-u-s-regions/), [Amazon Commits \\$10 Million to Restore and Conserve 4 Million Acres of Forest in the Appalachians and other U.S. Regions](https://www.amazon.com/press-releases/amazon-commits-10-million-to-restore-and-conserve-4-million-acres-of-forest-in-the-appalachians-and-other-u-s-regions/)

<sup>48</sup>For example, see: [S.1251 - 117th Congress \(2021-2022\): Growing Climate Solutions Act of 2021](https://www.congress.gov/bills/117/1251), [S.4451 - 116th Congress \(2019-2020\): Rural Forest Markets Act of 2020](https://www.congress.gov/bills/116/4451) and [Congressional Climate Camp #4: Federal Policies for Climate Mitigation and Adaptation Win-Wins \(April 2021\)](https://www.congress.gov/records/climate-camp-4-federal-policies-for-climate-mitigation-and-adaptation-win-wins).

<sup>49</sup>Design theorists Horst Rittel and Melvin Webber introduced the term “wicked problem” in 1973 to draw attention to the complexities and challenges of addressing planning and social policy problems, which can lack clarity in both their aims and solutions and are subject to real-world constraints that prevent multiple and risk-free attempts at solving them. Read about the 10 characteristics of wicked problems here: [What's a Wicked Problem? | Wicked Problem \(stonybrook.edu\)](https://www.stonybrook.edu/wicked-problem/) Also see this webinar: [Strategies for System Change and tackling wicked problems \(2/18/21\)](https://www.forestfoundation.org/en/webinar/2021/02/strategies-for-system-change-and-tackling-wicked-problems)

<sup>50</sup>Solutions may also be counterintuitive. For example, Project Drawdown determined that empowering women and girls represents the most impactful tool for achieving a climate-safe future. Among the 80 solutions evaluated for their potential to reverse global warming, educating girls and ensuring women have access to family planning resources ranked No. 6 and 7, respectively. By empowering women and girls globally, Project Drawdown calculated the avoidance of 120 billion tons of emissions by 2050. For further discussion, see: [The case for raising up women in climate tech | Greenbiz](https://www.drawdown.org/solutions) and Project Drawdown Solutions: <https://drawdown.org/solutions>

<sup>51</sup>For discussion, see: [Global Warming's Six Americas - Yale Program on Climate Change Communication](https://www.yale.edu/climatecommunication/)



Because of these conditions, a leadership vacuum exists for many of the actions needed to address climate change. Forest and forest product sectors have started to chart a course of policy action that considers all opportunities to address carbon mitigation objectives and targets.<sup>52</sup> In addition to policy action, realizing the full potential for forest and forest products will require leadership and innovation in the following areas:

- Soils & Agriculture: Addressing uncertainty and opportunities related to soil carbon through investments in research and practice, including continuing to pursue the potential for biochar from diverse feedstocks and other synergies across the agriculture sector.<sup>53</sup>
- Bioenergy Innovation & Carbon Capture: Committing to business investments and enabling policy to advance the responsible production and use of biomass energy and biofuels and adoption of carbon capture technologies.<sup>54</sup>
- Harvested Wood Products and Bio-Based Materials: Improving methodologies for accounting for carbon benefits of wood products to recognize the near-term (i.e., by 2030 and by 2050) benefits of product substitution, use of more bio-based materials in this decade to meet net-zero goals by mid-century, and actions to increase wood durability, reduce wood waste, and address end-of-life recovery and reuse opportunities.<sup>55</sup>
- People and Communities: Fully embracing the human dimensions of sustainability by acknowledging and working to address inequities that exist within environmental agendas and climate mitigation strategies.<sup>56</sup>



<sup>52</sup>See the work of the Forest Climate Working Group, <https://forestclimateworkinggroup.org/wp-content/uploads/2020/04/FCWG-Policy-Platform-V11.pdf>

<sup>53</sup>For discussion of this opportunity, see: [Survey and Analysis Of The US Biochar Industry](#), [Industrial biochar systems for atmospheric carbon removal: a review](#), [How to make money and sell biochar](#) - by Peter Olivier, and [Solutions from the Agricultural Sector](#) from Dr. John Quinn, Associate Professor of Biology, Furman University. Also see Appendix B for the list of [Seven Carbon Capture and Storage Technologies named by the IPCC](#).

<sup>54</sup>For discussion of this opportunity, see: [The potential for carbon-capture tech is captivating | Greenbiz](#), [DOE Invests \\$24 Million to Advance Transformational Air Pollution Capture | Department of Energy](#), [Carbon Capture Potential Spans US \(map\)](#), [CO2: An Important and Valuable Chemical For The Manufacturing Industry](#), and [Countries in the eastern UNECE region can play a leading role in CO2 storage, according to new study](#)

<sup>55</sup>For discussion of this opportunity, see: [On the trade-offs and synergies between forest carbon sequestration and substitution](#), [Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990–2019 \(fs.fed.us\)](#), [Georgia's Sustainable Development Carbon Registry](#), [Draft Catalogue of wood waste classifications in the UNECE Region](#), [Juno - reimagine recycling](#), [Annual biomass loss and potential value of urban tree waste in the United States](#), and [Understanding the Role of Embodied Carbon in Climate Smart Buildings](#)

<sup>56</sup>For discussion of this opportunity, see: [Ensuring Win-Wins Advance Environmental Justice](#) from Jacqueline Patterson, Senior Director, Environmental and Climate Justice Program, NAACP, Intertribal Timber Council, Center for Heirs Property Preservation, TAKING NATURE BLACK® | Audubon Naturalist Society, Forest History Society, "Unprecedented Seasons" lecture series, Women's Forest Congress, Free to Grow in Forestry

### *Commit to Solving the Energy Dilemma - Energy systems have to change now*

Achieving climate mitigation (i.e., net-zero goals) relies on significant and rapid change in energy systems.<sup>57</sup> A recent analysis of net-zero pathways for the US by 2050 concluded,

*"All blueprints for the United States agree on the key tasks for the 2020s: increasing the capacity of wind and solar power by 3.5 times, retiring coal plants, and increasing electric vehicle and electric heat pump sales to >50% of market share."<sup>58</sup>*

Bottom line, if action isn't taken within the energy sector, especially within this decade, whatever else is done to address climate change will be insufficient. The core of solving the climate change problem lies in reducing our reliance on fossil fuels, and forests and forest products have a role to play in the change that is necessary. The responsible production of biomass energy provides an immediate opportunity to reduce the use of fossil fuel energy sources as required to meet net-zero goals by mid-century. The use of a wide variety of wood products can also contribute to these goals, including as high carbon storage/low embodied carbon substitutes for concrete and steel in construction and as renewable substitutes for fossil plastics in many applications.

Furthermore, with regard to climate change strategies, research shows that:

*"...approximately one third of human-caused greenhouse gas emissions can be attributed to just a few 100 companies... some of the biggest global players in the energy, transport, mining, manufacturing, and consumer goods sectors... 25 publicly traded companies... account for more than 10% of global annual anthropogenic emissions."<sup>59</sup>*

Forests can and should play a role in many companies' carbon mitigation strategies, through material sourcing and transportation as well as energy system change.

### *Learn from Past Success - The best time to plant a tree was 20 years ago, the next best time is now*

The period of 2020-2050 could be the greatest forest and green infrastructure investment opportunity that has occurred in the US in nearly 100 years, comparable perhaps only to the response the US made to the ecological disaster of the dust bowl in the 1930s. In response to the conditions at that time, the US Congress declared soil erosion "a national menace", established the Soil Conservation Service in the Department of Agriculture, developed farm conservation programs and payment systems for farmers, and undertook the planting of 200 million trees in a 100-mile-wide zone from Canada to North Texas at an investment of \$75 million<sup>60</sup> over 12 years.<sup>61</sup>

There is an opportunity to plant 60 billion trees in the US by 2040 in ways that include reforestation, restocking, agroforestry, and urban forestry opportunities across the nation. The result could be the annual removal of 540 million tons of CO2 from a public investment of about \$4 billion annually (i.e., about \$7.40 per metric ton of CO2e).<sup>62,63</sup> For comparison, the Conservation Reserve Program (CRP) currently provides about \$2 billion annually to support private landowners' efforts to restore, enhance, and protect natural resources and wildlife habitats.<sup>64</sup>

The US has an opportunity to apply the lessons learned from history and leverage many decades of experience with landowner engagement to implement an inclusive and equitable approach to tree planting that will have lasting impact for climate change mitigation and many other measures of public benefit.<sup>65</sup> Planting trees isn't all we need to do to mitigate climate change, but it is something we know how to do now and an activity that will provide multiple benefits to the environment, economy and communities.<sup>66</sup>

<sup>57</sup>For discussion of this prioritization, see this presentation including Mauro Patriccione, Director General for Climate Action, for the European Commission: [Leadership in Our Time, Feb 26, 2021](#). Also see this domestic example of prioritized mitigation actions: [National Academy Publishes Study Showing How Georgia Could Halve Its Carbon Footprint \(28 July 2021\)](#)

<sup>58</sup>Williams, J. H., Jones, R., Haley, B., Kwok, G., Hargreaves, J., Farbes, J., et al. (2021). Carbon-neutral pathways for the United States. AGU Advances, 2, e2020AV000284. <https://doi.org/10.1029/2020AV000284>

<sup>59</sup>[Sustainable Business Review](#) (article starting on p24). Also see discussion of Scope 1, 2, and 3 emissions, such as this information: [Greenhouse Gases at EPA](#)

<sup>60</sup>\$75 million in 1930 is equivalent in purchasing power to about \$1.2 billion today ([U.S. Inflation Calculator](#))

<sup>61</sup>See: [FDR and the Dust Bowl - Forward with Roosevelt \(archives.gov\)](#) and [Timeline: The Dust Bowl | American Experience | Official Site | PBS](#)

<sup>62</sup>[Planting 60 Billion Trees in the U.S. | World Resources Institute \(wri.org\)](#)

<sup>63</sup>Globally, reforestation has the potential to sequester an estimated 253 gigatons CO2e between 2018 and 2100. <https://www.cdp.net/en/articles/forests/how-do-carbon-offsets-fit-into-a-net-zero-future>

## The Bottom Line

The forest sector has the expertise and core knowledge to lead in the definition, quantification, verification, and advocacy for the full abilities of forests and forest products as climate solutions.<sup>67</sup> This work must be done with partnerships and through collaborative engagement,<sup>68</sup> but the forest sector cannot wait for others to do the foundational work that is needed in defining the opportunity. Wicked problems require multiple parallel solutions and collaborative leadership models. Experiencing “messy” innovation and marketplace competition (even a bit of confusion and conflict) probably means we are on the right track. Everything from local and regional solutions<sup>69</sup> to global innovations<sup>70</sup> are relevant and necessary in this work. As the sector charts this course, this perspective should be incorporated:



We must collectively reject the myth of scarcity and embrace the reality of abundance, whether it be regenerative systems of food, regenerative design that we need for our buildings, or the regenerative nature of energy through clean energy. Our society was founded on practices of exploitation, extraction, domination, and displacement. We have to shift to a society rooted in principles and practices around regeneration, cooperation, and interdependence.

- Jacqueline Patterson, Senior Director, Environmental and Climate Justice Program, NAACP<sup>71</sup>

## Conclusion

Over the years, Dovetail Partners has reported on forest carbon and many dimensions of the science of sequestration. This report focused on forest carbon offsets: associated markets, their status, recent developments, and what is on the horizon, from a US perspective. The IPCC has identified five forest carbon pools, with an additional two pools to account for forest-derived products. The IPCC has also identified forestry related options for mitigating climate change that range from tree planting to forest management and the use of wood products, including as high carbon storage/low embodied carbon substitutes for concrete and steel in construction, soil carbon-enhancing biochar, and as replacements for fossil fuel and energy use.

These options provide the basis for forest carbon offset protocols and eligible projects. Due to private and public sector interest, the potential market for carbon offsets by 2030 could be up to 5 billion metric tons of carbon dioxide equivalent and up to two-thirds of the market could be served by natural climate solutions. However, current voluntary markets are only providing 8-13% of what the domestic market may demand within the decade and may need to grow by more than 15-fold by 2030 to support the 1.5°C pathway. Given projections for the future of US forests to be impacted by development and other negative forest health trends, significant investment is needed in policy actions, forest care and stewardship, and landowner engagement just to keep the climate mitigation capacities that currently exist in forests across the US much less to expand it. For the potential of forest carbon offsets in the US to be realized, there is a need to apply the history of large-scale tree planting to the scope of the climate change challenge, focus on changing energy systems as job number one, and define and advocate for the full range of solutions that trees and wood offer to all.



<sup>64</sup>USDA Announces Conservation Reserve Program Results | USDA

<sup>65</sup>For information about ensuring equity in tree planting efforts, see: [Tree Equity Score](#)

<sup>66</sup>Also see Appendix A for the list of *Seven Carbon Capture and Storage Technologies named by the IPCC* for additional priority, near-term actions.

<sup>67</sup>For further discussion, see: [The Forest Industry Should Embrace the Climate Change Conversation \(forest2market.com\)](#)

<sup>68</sup>One strategy is to understand and influence trends in allied sectors, for example architecture trends: [Five Trends on Track to Change Architecture in 2021](#). For collaborative approaches, see [#forestproud | A Community Keeping North America's Forests as Forests and Forest Climate Working Group](#)

<sup>69</sup>Promoting Locally Led Adaptation In Climate Action | Big Ideas Into Action Podcast | World Resources Institute (wri.org)

<sup>70</sup>Progress Index to Measure SDGs, SDG Knowledge Hub, A project by IISD and [Using Gross Ecosystem Product \(GEP\) to Value Nature in Decision Making](#)

<sup>71</sup>Ensuring Win-Wins Advance Environmental Justice from Jacqueline Patterson, Senior Director, Environmental and Climate Justice Program, NAACP

# Appendix A. (Revised September 2021)

## Comparison of Forest Carbon Programs – 8/16/2021

Source: [The Forestry Source Forestry Source September 2021 \(mydigitalpublication.com\)](https://www.mydigitalpublication.com)

Data in this chart have been compiled to show the various forest carbon programs that offer services geared toward small landowners. While some programs are in full operation, others are still in their early stages of roll-out. Please note that the data provided below are self-reported by the companies listed in the chart.

Program	Silviterra/Natural Capital Exchange (NCAPX)	Family Forest Carbon Program	Forest Carbon Works	Bluesource
<b>Lead Organization(s)</b>	Silviterra	The American Forest Foundation and The Nature Conservancy	NCX	Bluesource
<b>Partners</b>	Microsoft, Union Square Ventures, Version One, others	Funding Partners: Amazon.com, USFS, NRCs, Doris Duke Charitable Foundation. Technical Partners: Vermont FPR, Audubon Vermont, Vermont Woodlands Association, Vermont Tree Farm	AXA Impact Fund	Over 100 unique voluntary offset buyers and dozens of land conservation NGOs
<b>Description</b>	Transactional marketplace that allows sellers and buyers to submit bids and offers which are matched periodically. Platform is built over Silviterra's Basemap technology which claims to be able to measure every tree on every acre every year.	The program provides incentive payments to eligible family forest owners (30-2,400 acres) to implement sustainable forestry practices that increase carbon sequestration and timber production. Carbon produced from land enrolled in the program is available for purchase in the form of verified carbon credits.	Landowners with a minimum of 40 acres are eligible for no-cost, no fees for participants. Completes free carbon inventories of properties to determine eligibility and pays landowners annually for sequestering carbon.	Bluesource serves as a contingent fee, environmental attribute developer. Once a landowner hires them, Bluesource funds the full cost of project development and is only compensated once credits are issued and sold. They have applied this method across 70+ projects in the US and Canada covering 2.6M acres. They have sold approximately 1.0M voluntary forestry offsets per year in recent years
<b>Standard</b>	Verra - unverified	Verra - nearing verification	California Air Resources Board; Verified	Has used CAR IFM, CAR ACR, Verra IFM, CAR grasslands IFM, California ARB IFM, and ACR IFM. Most common methodology/standard today is ACR IFM
<b>Carbon Project Type(s)</b>	Deferred Harvest	Improved Forest Management	Improved Forest Management	IFM predominantly.

Practices or Services Funded	Landowners receive payments for deferring all or some of their harvest over the next 12 months.	1. Growing Mature Forests: promotes the growth of larger, higher quality trees by limiting harvesting over a 20-year contract period, in line with the landowner's management plan. 2. Enhancing Future Forests: promotes regeneration of new forests by having the landowner reduce competing vegetation following or preceding a regeneration harvest. *Specific to Pennsylvania and subject to change in Vermont	Forest Carbon Works membership benefits include: fully funded project development including inventory, verification, marketing, monitoring, and reporting; forestry services including forest management planning and harvest guidance; estate planning and conservation easement assistance and planning.	Landowners receive payments based on actual credits generated. Credits generated = the difference between landowner's management and a common practice baseline less deductions for uncertainty, leakage, and buffer pool contributions.
<b>Term</b>	1-year project term	Landowners commit to 10 - 20 year agreements, depending on the practice. Growing Mature Forests: 20-year contract. Enhancing the Future Forests: 10-year contract. A permanent conservation easement if not required. The program meets market permanence requirements at the landscape level through aggregation of many landowners across a region and through practices that incentivize a shift to more productive and sustainable management in the long run.	25-year crediting period and a 100-year monitoring period. 25-year crediting periods are renewable up to two times (75 years total)	ACR IFM methodology requires a 40 year commitment to maintain stocking at the level which the land owner has received credits for. Bluesource's contract with the landowner starts at 10 years but can be renewed.
<b>Potential Revenue</b>	\$8-10 per acre (estimated)	\$100-\$215 per acre over the life of the contract, depending on the practice. *Specific to Pennsylvania and subject to change in Vermont	Payments for viable projects range from \$10 per acre per year to \$100+ per acre per year. Members receive annual payments during 6 year periods with the options to renew over the 25-year crediting period.	Approximately \$150 - \$1000 per acre over ten years depending on stocking. Bluesource will provide free feasibility assessments for high probability projects
<b>Geography</b>	Southeast U.S. in 2021, continental U.S. thereafter.	A pilot is underway in northwest and central Pennsylvania. Expanding throughout Central Apps, New England, and Northwoods of the Upper Midwest in 2021.	Entire U.S. excluding Hawaii and parts of Alaska. Projects are currently underway in Oregon, Vermont, and Maine. Inventories have been completed in 15 states.	Forested lands in the US and Canada
<b>Type of Support</b>	There is no cost to landowners. NCAPX simply matches buyers and sellers, manages payments, and performs annual measurement.	Funding (incentive payments to implement practices) and expert assistance with project development, forest management planning, verification	Forest Carbon Works membership benefits include fully funded project development including inventory, verification, marketing, monitoring, and reporting; forestry services including forest management planning and harvest guidance; estate planning and conservation easement assistance.	No cost to landowners

<b>Who is Eligible?</b>	All forest owners.	Family forest owners with 30-2,400 acres	Landowners owning a minimum of 40 acres. Premium Membership options available for landowners owning 1,200+ acres	Landowners with 5000 acres or more. This may drop to 1000 acres depending on new ACR small forest owner protocol. OR landowners who aggregate their holdings with an intermediary via a 40 year timber deed to reach 5000 acres.
<b>Link</b>	<a href="http://silviaterra.com/ncapx">silviaterra.com/ncapx</a>	<a href="http://forestfoundation.org/family-forest-carbon-program-familyforestcarbon.org">forestfoundation.org/family-forest-carbon-program-familyforestcarbon.org</a>	<a href="http://forestcarbonworks.org">forestcarbonworks.org</a>	<a href="http://bluesource.com">bluesource.com</a>
<b>More Information</b>	First transactions expected in March 2021.		<a href="mailto:inquire@forestcarbonworks.com">inquire@forestcarbonworks.com</a>	
<b>Contact</b>	Jeff Wright jeff@silviaterra.com 843-575-9916	Jim Shallow jim.shallow@tnc.org 802-229-4425 x104	Sarah Ford, Regional Forester sarahf@forestcarbonworks.com 802-391-3133	Aaron Paul 207-837-2571 apaul@bluesource.com

Updated by Tim Stout – Northam Forest Carbon / Doug Baston – Maine Woodlands Owners Assoc  
Please contact Tim Stout @ stoutim@gmail.com or 617-889-1011 with any questions.  
15-Aug-21

## Appendix B.

### Seven Carbon Capture and Storage Technologies named by the International Panel on Climate Change

(Summary from Scientific American; Jan 2019, p54-59; based on Negative Emissions—Part 2: Costs, Potentials and Side Effects,” by Sabine Fuss et al., in Environmental Research Letters, Vol. 13, No. 6, Article No. 063002; June 2018)

1. Afforestation and reforestation: lowest cost option at 0 to \$40/ton with potential for 0.5 to 3.5 Gigatons of Carbon Equivalent (GTcE) per year in 2050.
2. Bioenergy with Carbon Capture and Storage (BECCS): energy generation using renewable resources as the fuel, but requires tailpipe carbon capture and underground storage. Modestly expensive at 100 to 200\$/ton, with the potential to store 0.25 to 4GTcE/yr by 2050.
3. Biochar: from primarily soil incorporation; \$38 to 120\$/ton with the potential to sequester 0.25 to 2GTcE/yr by 2050.
4. Enhanced Weathering: A relatively expensive solution at \$50 to \$600/ton but with the potential for up to 5.25GTcE storage in 2050.
5. Direct Air Capture: assuming the technology can be developed, costs of 100 to 300\$/ton are projected with the potential to store up to 5GTcE/yr.
6. Ocean Fertilization: is relatively inexpensive (\$30/ton projected) with relatively high potential of up to 12GTcE/yr by 2050, but the technology presented sufficient environmental risks the option was dropped from detailed consideration in Fuss' study.
7. Soil Carbon Sequestration: A highly variable cost of 0 to \$200/ton, but with the potential for up to 6GT storage in 2050.



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Dovetail Partners' mission is to provide authoritative information about the impacts and trade-offs of environmental decisions, including consumption choices, land use and policy alternatives.

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