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Agency of Natural Resources
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MEMORANDUM

TO: Sen. Robert Starr, Chair, Senate Committee on Agriculture
Sen. Christopher Bray, Chair, Senate Committee on Natural Resources and Energy
Rep. Carolyn Partridge, Chair, House Committee on Agriculture and Forestry
Rep. Amy Sheldon, Chair, House Committee on Natural Resources, Fish, and Wildlife

FROM: Michael Snyder, Commissioner, Dept. of Forests, Parks, and Recreation

DATE: January 15, 2021

RE: Act 129 (H.656) of 2020 – Written Testimony on the Status of Forest Carbon Projects and Programs in Vermont

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This memo, in response to section 32 of Act 129 (H.656) of 2020, provides written testimony that includes a summary of the education and outreach on forest carbon conducted by the Department of Forests, Parks, and Recreation; the status of enrolling state lands in a carbon market; considerations on establishing a public-private partnership to facilitate enrolling Vermont forestlands in a carbon market; and a summary of the viability and health of carbon markets nationally and in the state.

Also per the Act, the Department is prepared to provide oral testimony as well.

Legislative Mandate

The Vermont General Assembly, as part of Act 129: An Act Relating to Miscellaneous Agricultural Subjects made the following requests:

On or before January 15, 2021, the Commissioner of Forests, Parks and Recreation (Commissioner), shall provide written and oral testimony to the Senate Committees on Agriculture and on Natural Resources and Energy and the House Committees on Agriculture and Forestry and on Natural Resources, 9 Fish, and Wildlife regarding the status of forest sequestration projects and programs in the State. The testimony shall address:

(1) a summary of the education and outreach conducted by the Commissioner and other relevant parties for the public regarding forest sequestration, including information provided or available to the public regarding requirements for selling forest carbon credits, descriptions of the different markets and registries for carbon credits, procedures for establishing a forest carbon sequestration project on private land, and information describing the compatibility between forest carbon credits and State programs;

(2) the status of action by the Commissioner or other State entity in enrolling State land in a carbon market, and if State land has been enrolled in a carbon market, the basis and terms of the enrollment agreement;

(3) a summary of the efforts by the Commissioner to establish a partnership between the Agency of Natural Resources and one or more experienced private organizations to establish a statewide team to minimize the costs and maximize the benefits of enrolling public and private land into a carbon market; and

(4) a summary of the viability and health of carbon markets nationally and in the State and the economic feasibility and benefits to private and public landowners of entering carbon markets.

(1) Summary of the Education and Outreach

Recognizing the need for easy-to-understand information on the forest carbon cycle, key terminology and concepts, forest carbon offset markets, and the status of Vermont's forest carbon pools and fluxes, Department of Forests, Parks, and Recreation (FPR) staff have drafted informational documents for use by the public, policymakers, foresters, and managers, and for education and outreach purposes for FPR staff and others. Information and data from these resources have been used in a presentation to the Global Warming Solutions Act's Climate Council and incorporated into public webinars. These educational resources will be posted on the FPR website, are included as appendices to this testimony, and an outreach strategy is being developed. Below is an overview of these resources:

1. What is Forest Carbon?

The first of these documents is an informational guide designed to help people learn about the forest carbon cycle and key terminology (Figure 1). ***What is Forest Carbon? (Appendix 1)*** contains definitions for terms like carbon sequestration and storage, describes how scientists estimate and measure forest carbon, and explains how forest carbon varies by forest type, age, and condition. It contains graphical diagrams to help convey key messages.

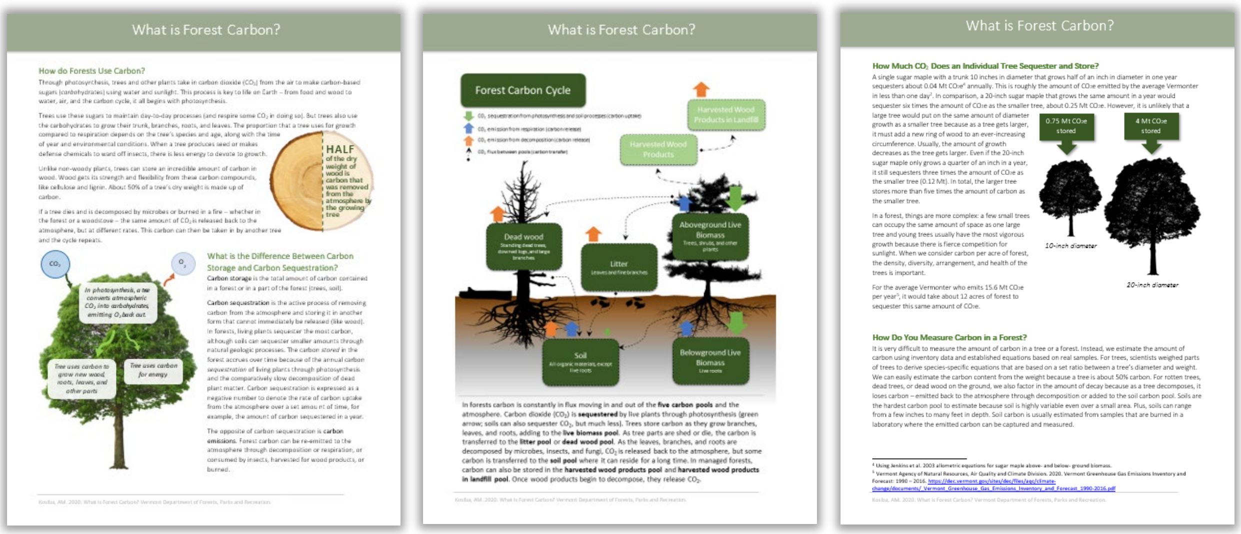
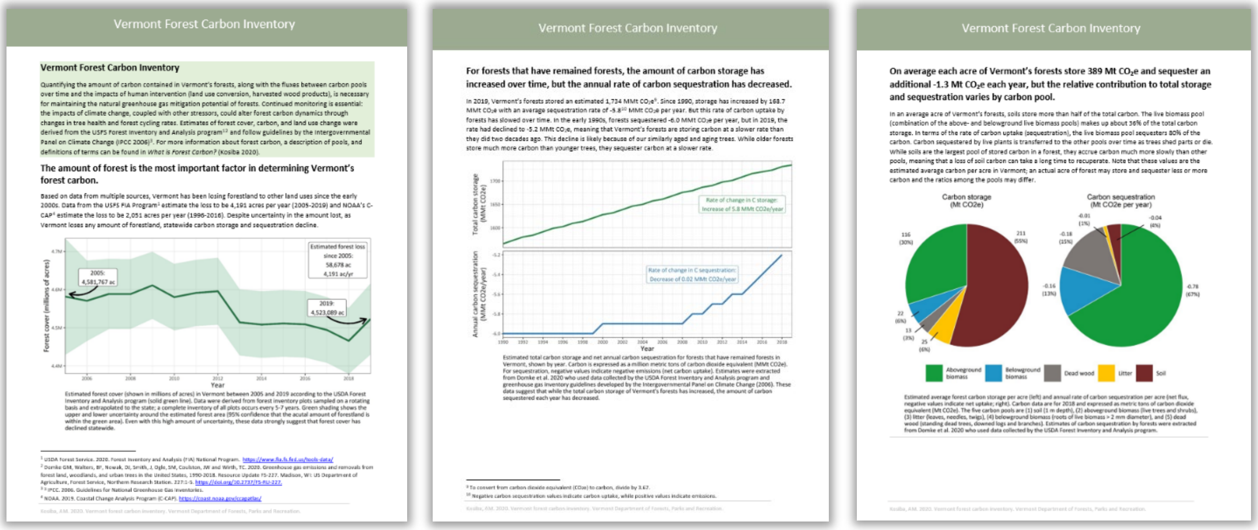


Figure 1. Select pages from ***What is Forest Carbon?*** an informational guide to understanding how carbon moves through forests, forest carbon pools, key terminology, and differences between forest types.

2. Vermont Forest Carbon Inventory

The second document is a summarized carbon inventory for the state of Vermont's forestland (Figure 2). The ***Vermont Forest Carbon Inventory (Appendix 2)*** presents data on statewide forestland conversion, rates of carbon storage accrual in each of the five forest carbon pools, and historical and current rates of carbon sequestration derived from the most recent USDA Forest Service's Forest Inventory and Analysis program data. Each graph is accompanied by interpretive information to help the reader understand and navigate the data.



Vermont Forest Carbon Inventory

Vermont Forest Carbon Inventory

The amount of forest is the most important factor in determining Vermont's forest carbon.

Vermont Forest Carbon Inventory

For forests that have remained forests, the amount of carbon storage has increased over time, but the annual rate of carbon sequestration has decreased.

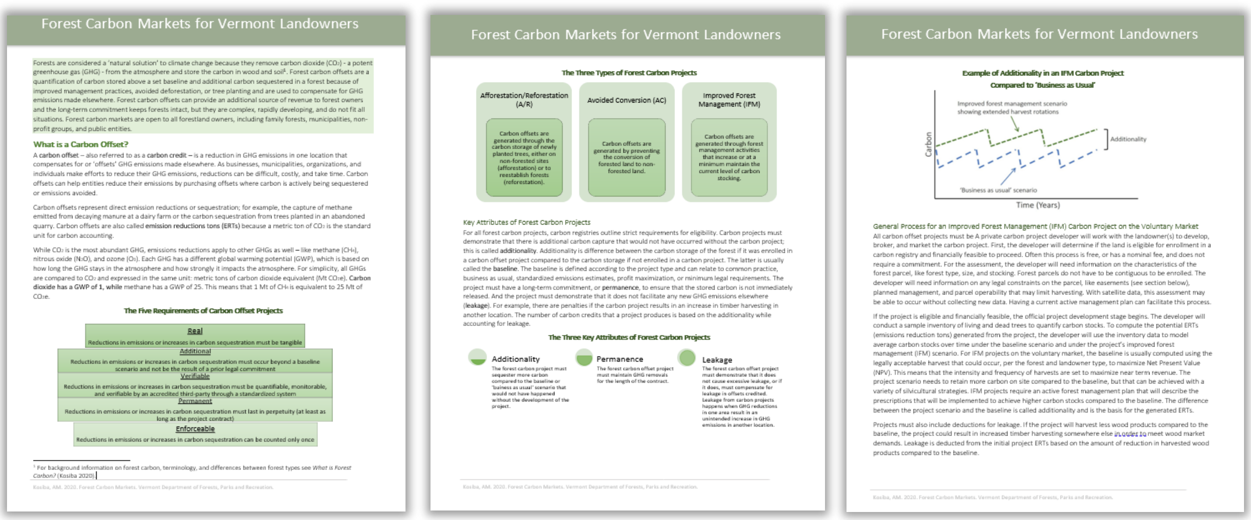
Vermont Forest Carbon Inventory

On average each acre of Vermont's forests store 389 Mt CO_2e and sequester an additional -1.3 Mt CO_2e each year, but the relative contribution to total storage and sequestration varies by carbon pool.

Figure 2. Select pages from the ***Vermont Forest Carbon Inventory***: an analysis of historical and current forest carbon storage and sequestration, carbon fluxes from land-use change, and per acre averages by carbon pool.

3. Forest Carbon Markets for Vermont Landowners

We compiled a guide to understanding forest carbon offsets and markets for Vermont forestland owners (Figure 3). *Forest Carbon Markets for Vermont Landowners (Appendix 3)* describes how carbon offsets are quantified and commoditized, the compatibility of carbon markets with other forestland policies and programs (e.g., Vermont's Use Value Appraisal ("current use") program, Forest Legacy program and other conservation easement agreements, and the process of developing a carbon offset project. It also provides compiled information on the current programs available to Vermont landowners, minimum acreages, and contract timelines for landowners to make the best decision for their interests. The resource also provides a current list of forest carbon project developers available to Vermont landowners.



Forest Carbon Markets for Vermont Landowners

Forest Carbon Markets for Vermont Landowners

Forest Carbon Markets for Vermont Landowners

Figure 3. Select pages from ***Forest Carbon Markets for Vermont Landowners***: an overview of carbon offsets, important definitions, project requirements and general process, and options for small landowners.

(2) Status of Action in Enrolling State Land in a Carbon Market

In a joint leadership effort between the FPR and the Department of Fish and Wildlife (FWD), we have established an Agency of Natural Resources (ANR) Carbon Market Work Group to advance our efforts toward potentially enrolling some ANR land in a carbon offset market. To date, the ANR Carbon Market Work Group has met twice (12/29/20 and 1/11/21). By summer 2021, the Work Group will establish goals and motivation for any potential enrolment, identify the constraints on our ability to proceed with enrollment, outline our criteria for selecting parcel(s) for consideration, and identify the resources we need to support this effort. The Work Group will make recommendations to the FPR Commissioner and the FWD Commissioner for any ANR land(s) to enroll and outline next steps for enrollment, including needs and challenges, if deemed appropriate and feasible.

The Work Group is composed of the following ANR staff:

- Hannah Phillips, State Lands Administration Program Manager, FPR Division of Lands Administration and Recreation, Co-chair
- Alexandra Kosiba, Climate Forester, FPR Division of Forests, Co-chair
- Jane Lazorchak, Public Lands Section Chief, FWD Wildlife Division, member
- Paul Szwedo, State Lands Forester, FPR Division of Forests, member
- Tim Morton, Stewardship Forester, FPR Division of Forests, member

(3) Efforts to Establish a Partnership to Support Enrolling in Carbon Markets

Forest carbon project development pathways

Because forest carbon project development is expensive and a proportion (30-40%) of the generated revenue leaves the state through project developers, field inventory crews, and third-party verifiers, there has been interest in exploring an alternative model for Vermont. One proposed idea is the creation of a public-private partnership whereby the non-profit sector and the state (via ANR) collaborate on forest carbon project development. This concept arose from the recent Cold Hollow to Canada (CHTC) forest carbon project. This project involved partnerships between three non-profits groups, the Vermont Land Trust (VLT), CHTC, The Nature Conservancy (TNC), and private, out-of-state companies, including a carbon developer (Spatial Informatics Group, SIG), forest inventory crew, third-party verifier (SGS), and carbon registry (American Carbon Registry). VLT oversaw the legal and administrative components. TNC marketed selling the offset credits. SIG oversaw and hired the forest inventory crew, modeled the carbon stocks under the baseline and project scenarios, and arranged the third-party verification with SGS. SIG will continue to oversee the periodic forest inventories and verification requirements through the 40-year contract. According to VLT, 30% of the revenue from selling offsets from the CHTC carbon project will go to the aforementioned non-profit and private sector groups for the marketing, project development, and administration. The remaining 70% of the revenue will go to the landowners. However, these values are approximate; VLT is currently working on compiling the final project costs.

While the CHTC project was unique due to oversight from local non-profit groups, because the development of a carbon project is complex and details are often proprietary, the use of private companies was necessary. In the US, there are many established and highly-experienced carbon developers and third-party verifiers, a number of which have experience with forest carbon projects in the Northeast. Because of this, establishing a program in ANR to develop forest carbon projects may be inefficient. At this time, we recommend exploring ways to retain some of the revenue from carbon projects in state. Possible options include: attracting carbon offset businesses to establish in the state, capitalizing on the charismatic nature of Vermont's forests for carbon projects through higher revenue generation, and/or promoting the use of local forest inventory crews.

Novel opportunities for forest carbon projects

Added to the complexities of project development, the carbon market sector is rapidly growing (see more specific details under section 4 below), primarily driven by the private sector's use of carbon offsets to reduce its carbon footprint and respond to shareholder demands, but also by the increasing number of state governments that are setting greenhouse gas (GHG) reduction targets and growing interest of forestland owners to sell forest carbon. This demand has resulted in many new pathways for forest carbon projects that differ in methodology from established protocols. Because of these developments and complexities, we see the best option moving forward as supporting efforts to create alternative carbon marketplaces and standardization as well as supporting programs recently or currently in development (see section 4 below).

Recently, a four US Climate Alliance (USCA) states in the Northeast -- Maine, New York, Massachusetts, and Vermont -- have gathered to explore the possible development of a regional market-based system or other financing mechanism to promote investment in carbon sequestration pathways. FPR Commissioner Snyder and FPR Climate Forester Alexandra Kosiba are participating in this work group. While the current focus is on forest carbon sequestration, the target pathways could include sequestration activities on other natural and working lands (NWL), like agricultural lands, or mechanical carbon capture and storage. The work group has articulated that this market or other financing mechanism must support on-the-ground implementation of activities that contribute to statutory and policy greenhouse gas mitigation and sequestration goals. The USCA has provided Claire Jahns, USCA Senior Advisor, to act as facilitator and project manager to support the work group in the initial phase of concept development at 5-10 hours per week through March 2021. The facilitator will draft a concept paper that articulates goals, refines the market landscape, classifies potential roles for state governments, and identifies next steps and resource needs by the end of March 2021.

Nationally, there is a recognized need for regulation, standardization, and transparency in the voluntary carbon market. The US Congress is currently working on a bill that would provide these components under the Growing Climate Solutions Act[1], a bipartisan policy by Senators Braun and Stabenow. This act would establish a USDA certification for consultants, developers, and third-party verifiers in both forests and agriculture carbon projects, a Greenhouse Gas Technical Assistance Provider and Third-Party Verifier Certification Program, and an online marketplace for buyers and sellers. The US Congress is also proposing the Rural Forest Market Act[2] that would provide funding for forest and agriculture carbon projects. Even if these bills do pass, implementation may take several years to fully realize.

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[1] https://www.braun.senate.gov/sites/default/files/2020-06/Growing%20Climate%20Solutions%20Act%20One%20Pager_0.pdf
[2] https://www.agriculture.senate.gov/imo/media/doc/Rural%20Forests%20Factsheet_Final.pdf

(4) Summary of the viability and health of carbon markets nationally and in Vermont

Carbon markets for Vermont landowners

California's Cap-and-Trade regulatory market is likely not feasible for enrollment of either public or private forestland in Vermont. This is because the number of carbon offsets (also called ERTs, emissions reductions tons) that can be purchased without a direct environmental benefit to the state of California has been reduced in 2021 by the California Air Resources Board (CARB)[3]. An additional hurdle for projects developed under the CARB registry is the long contract period (100 years) compared to other carbon registries in the voluntary market (e.g., under the American Carbon Registry)[4]. The Regional Greenhouse Gas Initiative (RGGI) regulatory market, in which Vermont participates, does not currently include forest carbon projects, likely because of the low selling price of carbon offsets and high development costs under the RGGI protocols that make forest carbon projects financially unfeasible. Because of the limitations of California's regulatory market and lack of options in RGGI, the more viable route for Vermont's public and private forestland is through the voluntary carbon market.

While the voluntary market is currently the best route for Vermont forestland owners, there are still challenges. The project development, forest inventory, and third-party verification can be costly. At current carbon offset prices, the voluntary carbon market is only financially feasible for projects of at least 2000 acres[5]. One option for smaller landowners is project aggregation of multiple landowners to meet the size threshold. However, there are limited examples of project aggregation for forestland. Vermont has the first forest carbon aggregation project in the country: The Cold Hollow to Canada (CHTC) carbon project covers 7,500 acres in Franklin and Lamoille counties[6][7]. With project aggregation comes additional hurdles to project development, like the administrative, technical, and legal complexities of aggregating a project with multiple landowners. VLT created an LLC to oversee the project and detailed contracts were created to cover the legal considerations of a landowner terminating the project early without penalty to the remaining landowners. These challenges existed despite key benefits associated with the CHTC project: landowners who had a pre-existing and robust relationship with each other, a single forester overseeing all parcels, forestland enrolled in the state's current use program, and common landowner goals. Though a partnership with TNC, the project was able to secure high-profile investments from Amazon[8] . Because of the appeal of this project, outside investments, and added co-benefits (flood resilience, wildlife habitat), the carbon offsets generated from the CHTC project sold for about twice that of other projects in the region[9]. A final report on the CHTC project is currently being drafted by project personnel that will provide more information on forest carbon project aggregation.

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[3] https://ww2.arb.ca.gov/our-work/programs/compliance-offset-program/direct-environmental-benefits

[4] Keeton WS, VanDoren W, Kerchner C, and Fuqua M. 2018. Vermont Forest Carbon: A Market Opportunity for Forestland Owners. https://www.vlt.org/wp-content/uploads/2018/07/Vermont_Forest_Carbon.pdf

[5] Keeton WS, VanDoren W, Kerchner C, and Fuqua M. 2018. Vermont Forest Carbon: A Market Opportunity for Forestland Owners. https://www.vlt.org/wp-content/uploads/2018/07/Vermont_Forest_Carbon.pdf

[6] https://vlt.org/forestcarbon

[7] https://vlt.org/forests-wildlife-nature/local-solution-global-impact-forest-carbon

[8] https://press.aboutamazon.com/news-releases/news-release-details/part-its-plan-be-net-zero-carbon-2040-amazon-commits-10-million

[9] https://vermontbiz.com/news/2020/august/06/can-vermont%E2%80%99s-forests-help-save-planet

In addition to project aggregation, the carbon market environment is rapidly evolving to include other options for smaller forestland owners. In a partnership between The Nature Conservancy and The American Forest Foundation, the Family Forest Carbon Program[10] is a pay-for-practice program with two forest management options for landowners with a minimum of 20 acres: Growing Mature Forests and Enhancing Future Forests. Inventory costs are significantly reduced through use of the National Forest Inventory data from the US Forest Service as the baseline used to show additional carbon accrual. Finite Carbon is releasing its Core Carbon[11] program in early 2021 that allows projects with as few as 40 acres to enroll and provides an on-line platform to visualize data and project progress. The New England Forestry Foundation is developing a pay-for-practices program that incentivizes increased tree stocking where it is lacking. This program will be piloted in Maine. Currently none of these programs is currently available for Vermont landowners, however, the Family Forest Carbon Program has piloted a project in western Massachusetts and southern Vermont.

Economic feasibility of forest carbon projects

Because offsets are bought and sold by private companies, the developers do not divulge the actual selling price for a specific project's carbon offsets. However, these prices are estimated by the non-profit group Ecosystem Marketplace via voluntary surveys. According to Ecosystem Marketplace, carbon sales on the voluntary market have been strong in 2020, despite the COVID-19 pandemic[12]. Prices for offset projects with Nature-Based Solutions (NBS) and Natural Climate Solutions (NCS), like forest carbon projects, increased 30% since 2019. However, in that same time, the number of offsets from NBS/NCS projects declined 28%. Despite the lower number of these offsets compared to offsets from renewable energy, the price of NBS/NCS projects was nearly two times that of renewable energy offsets. Some of this increase in offset price comes from the strong market for forest management projects in developing counties (REDD+[13]). The average price in 2019 for forestry and land use projects around the world was $4.3 per offset (see table below). It is widely acknowledged that forest carbon prices are too low and not representative of the social cost of carbon. A 2013 report from Vermont speculated that the price of carbon offset would be over $70 in 2020[14], but that has not materialized. As demand for carbon offsets grows, the price of a carbon offsets is expected to increase[15]. When that happens, smaller projects will become more economically viable.

Table 1. Voluntary Offset Prices and Volumes in 2019. Volume (in million metric tons of carbon dioxide equivalent), average price per offset, and associated total value for projects on the voluntary carbon market according to Ecosystem Marketplace[1]. Note that as there is no centralized

[10] https://www.familyforestcarbon.org/

[11] https://corecarbon.com/

[12] Forest Trends' Ecosystem Marketplace. Voluntary Carbon and the Post-Pandemic Recovery. State of Voluntary Carbon Markets Report, Special Climate Week NYC 2020 Installment. Washington DC: Forest Trends Association [2020 September 21]

[13] REDD+ refers to 'reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries'

[14] Saligman L, Russell-Roy E, Keeton W, Danks C, Gunn J, and Machin B. 2013. Can rehabilitative forestry and carbon markets benefit degraded forestland? A case study from Northeastern Vermont. Final Report Prepared for Vermont Natural Resources Conservation Service Conservation Innovation Grant # 69-1644-09-02 http://www.uvm.edu/rsenr/wkeeton/pubpdfs/Rehabilitative%20Forestry%20&%20Carbon%20Markets%20Final%20Report%20_.pdf

[15] Tucker, Will. Debunked: Eight Myths About Carbon Offsetting https://www.ecosystemmarketplace.com/articles/debunked-eight-myths-carbon-offsetting/ [2019 September 19]

repository for price and volume data from the voluntary market, Ecosystem Marketplace gathers data by survey such that these values may not represent all sales. Image from Ecosystem Marketplace[1].

	2019		
	VOLUME $MtCO_2e$	AVERAGE PRICE	VALUE
RENEWABLE ENERGY	42.4	$1.4	$60.1 M
FORESTRY AND LAND USE	36.7	$4.3	$159.1 M
WASTE DISPOSAL	7.3	$2.5	$18.0 M
HOUSEHOLD DEVICES	6.4	$3.8	$24.8 M
CHEMICAL PROCESSES/ INDUSTRIAL MANUFACTURING	4.1	$1.9	$7.7 M
ENERGY EFFICIENCY/ FUEL SWITCHING	3.1	$3.9	$11.9 M
TRANSPORTATION	0.4	$1.7	$0.7 M

Actual prices for forest carbon offsets on the voluntary market are variable, and higher prices are being seen for “charismatic” projects, like forest projects that have additional co-benefits (e.g., protection of biodiversity, wildlife, water). Currently, the highest paying forest project type is Improved Forest Management (IFM), which would likely be the most dominant forest carbon project type for Vermont forestland owners. Multiple sources have indicated the forest carbon projects are attractive to emitters because many large companies (e.g., Amazon, BP oil, JetBlue) are looking to offset emissions and boost public perception of their brand, particularly with forest carbon projects that have a conservation impact. The Ecosystem Marketplace report speculates that brands buy offsets close to home to demonstrate impact to their consumers and bolster their “social license to operate” in a country or region[1]. Having more companies from New England seeking to purchase forest carbon offsets in New England could increase the price.

From the perspective of emitters, there is interest in purchasing carbon offsets that achieve carbon sequestration (i.e., net increase in carbon storage) rather than offsets that represent the preservation of carbon stocks (i.e., avoided emissions). Offsets that represent a net increase in carbon sequestration may be more straightforward to apply to emissions reduction targets and can be more easily quantified than avoided emissions. Avoided emissions, while important for mitigating climate change, are often theoretical and can be more difficult to apply to emissions reduction targets.

In New England and Vermont, forest carbon offset projects have sold for higher prices than indicated in the Ecosystem Marketplace report that compiles global carbon offset data. In New England, approximate revenue for a forest owner depends on many factors, like site conditions, tree stocking, and removals, as well as marketing and outside sponsorship. On average, one carbon offset from a New England based improved forest management (IFM) project on the voluntary market has sold for about $10, but some projects have garnered higher prices. While the CHTC carbon project has not divulged the price that Amazon has paid for carbon offsets, estimates are that the price may be closer to $15-20 per offset.

Another example comes from Pachama[16], a platform for buying carbon offsets. On this site, a single carbon offset from a bundle of four long-term IMF forest projects in New England, which includes the Middlebury College's Breadloaf carbon project, costs $12.30 to purchase [as of 10/6/20]. Assuming that the development, inventory, and third-party verification costs are 40%, this would mean revenue to the landowner of $7.38 per offset sold. Based on an assessment of IFM carbon projects listed on public registries and located in New England, projects have been awarded anywhere from 0.5-4 carbon offsets per acre per year during the first 20-year crediting period (the number of carbon offsets usually decline in the second 20-year crediting period). Combining these values (per offset price and number of offsets credited per acre) could mean $3.5-$28 per acre per year for the first 20 years.

Table 2. List of current forest carbon projects listed on public registries. The American Carbon Registry, Verified Carbon Standard, and Climate Action Reserve registries were queried for projects located in Vermont. Only three projects are currently listed [as of 12/17/21] although there are more projects located in Vermont under development. IFM: improved forest management

Project Developer	Project Name	Project Type	Verifier	Project Site Location	Acres
Blue Source	Middlebury College's Breadloaf	IFM	SCS Global Services	Middlebury, VT	2670
Blue Source	The Nature Conservancy's Burnt Mountain	IFM	SCS Global Services	Montgomery, VT	5300
Vermont Land Trust and Spatial Informatics Group	Cold Hollow to Canada Carbon	IFM	SCS Global Services	Franklin and Lamoille counties, VT	7500

Benefits to private and public landowners of entering carbon markets

Revenue generated from a forest carbon project could be considerable depending on the acres of forestland enrolled and the current selling price of a carbon offset. This additional forest revenue could be used by the landowner to help pay for other conservation goals and forest management, for example, road upgrades, trail maintenance, invasive plant removal, timber stand improvement, or additional land acquisition. The most compelling reason to enroll in a forest carbon project is as a source of revenue for forestland that can complement ongoing forest management including commercial timber sales. A secondary benefit is that forest carbon projects essentially conserve the forest for the length of the project contract period (current project time requirement varies from 20-100 years).

[16] https://pachama.com/

Appendix 1: What Is Forest Carbon?

The carbon cycle

The carbon cycle is the key to life on Earth. Through natural processes, carbon is exchanged among living organisms, soil, rocks, water, and the atmosphere. However, humans have disrupted the carbon cycle by burning fossil fuels and disturbing ecosystems, resulting in a significant increase in emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) into the atmosphere where they alter the Earth's energy balance and cause climate change. Because CO_2 is removed from the atmosphere through photosynthesizing plants, forests and other plant-based ecosystems are vital in maintaining the carbon cycle.

How do forests use carbon?

Through photosynthesis, trees and other plants take in CO_2 from the air to make carbon-based sugars (*carbohydrates*) using water and sunlight, releasing oxygen to the atmosphere in the process. Trees use these sugars to maintain day-to-day processes (and respire some CO_2 in doing so). But trees also use carbohydrates to grow their trunk, branches, roots, leaves, flowers, seeds, and fruits. The proportion that a tree uses for growth compared to respiration depends on the tree's species and age, along with the time of year and environmental conditions. When a tree produces seeds or makes defense chemicals to ward off insects, there is less energy (carbohydrates) to devote to growth.

Unlike non-woody plants, trees can store an incredible amount of carbon in wood. Wood gets its strength and flexibility from these carbon compounds, like cellulose and lignin. About 50% of a tree's dry weight is made up of carbon.

If a tree dies and is decomposed by microbes or burned in a fire – whether in the forest or a woodstove – CO_2 is released back to the atmosphere but at different rates. This carbon can then be taken in by another tree and the cycle repeats.

What is the difference between carbon storage and carbon sequestration?

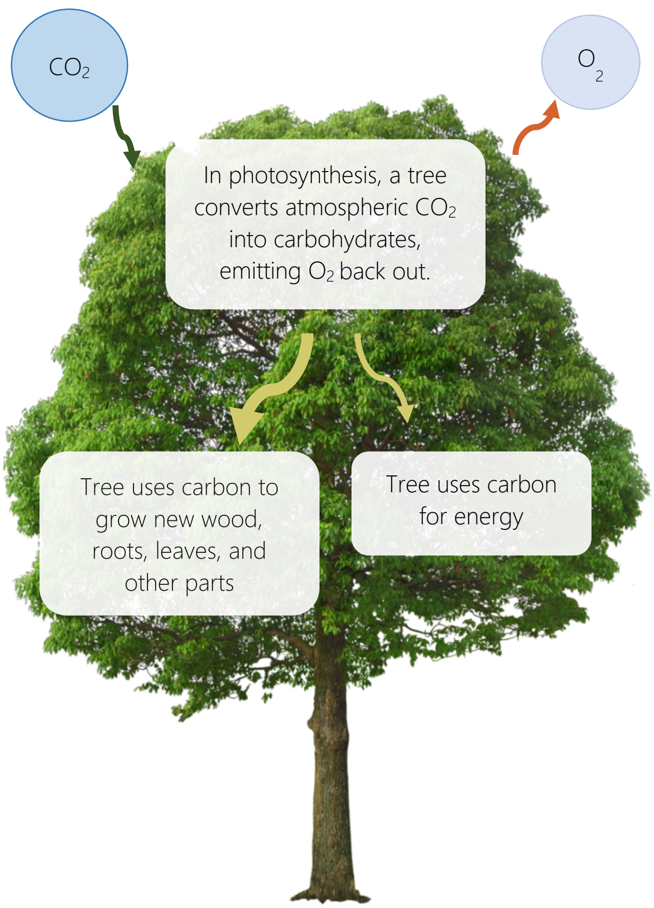
Carbon storage is the total amount of carbon contained in a forest or a part of the forest (trees, soil).

Carbon sequestration is the process of removing carbon from the atmosphere and storing it in another form that cannot immediately be released, like wood. It is the rate of uptake of carbon from the atmosphere. In forests, living plants sequester the most carbon, but soils can sequester smaller amounts through natural geologic processes. The carbon *stored* in the forest accrues over time because of the annual carbon *sequestration* of living plants through photosynthesis and the comparatively slow decomposition of dead plant matter. Carbon sequestration is expressed as a negative number over a unit of time (e.g., the amount of carbon sequestered in a year). Carbon sequestration is expressed as a negative value because it indicates the removal of CO_2 from the atmosphere, such that there is less CO_2 in the atmosphere to contribute to climate change.

Carbon emissions are the opposite of carbon sequestration. It is the rate of CO_2 released to the atmosphere. Forest carbon can be re-emitted to the atmosphere through decomposition, respiration, or combustion. The rate of carbon emissions is expressed as a positive number per unit of time because when CO_2 is emitted to the atmosphere, the amount of CO_2 in the atmosphere increases.

In a forest ecosystem, the combination of carbon sequestration and carbon emissions is the **net carbon flux** or the change in carbon storage over time. In other words, net flux accounts both for the uptake of CO_2 by live plants and soils, for emissions of CO_2 due to respiration, decomposition, and disturbances, and for the transfer of carbon to other parts of the forest.

When carbon flux is a negative number (less than zero), the forest sequestered more CO_2 than it emitted. This is called a **carbon sink** and the total carbon storage of the forest will increase by the amount sequestered. This is the current status of Vermont's forests.



When carbon flux is a positive number (greater than zero), the forest emitted more CO_2 than it took in. This is called a **carbon source** and the total carbon storage of the forest will decrease by the amount emitted. This can occur if a large amount of carbon was released from the forest due to land clearing or fire, or if the trees were not able to sequester as much carbon because they were injured or killed by insects or disease. If the forest can regrow, it can quickly return to being a carbon sink.

We want to make sure that forests store a large amount of carbon and that the annual rate of carbon sequestration is high, however, these two processes peak at different stages of forest development. Older forests store more carbon than younger forests, but they sequester it at a slower rate. Age diversity within a forest and across the landscape is the best way to maximize both storage and sequestration, plus diversity is a good strategy for climate resilience, too.

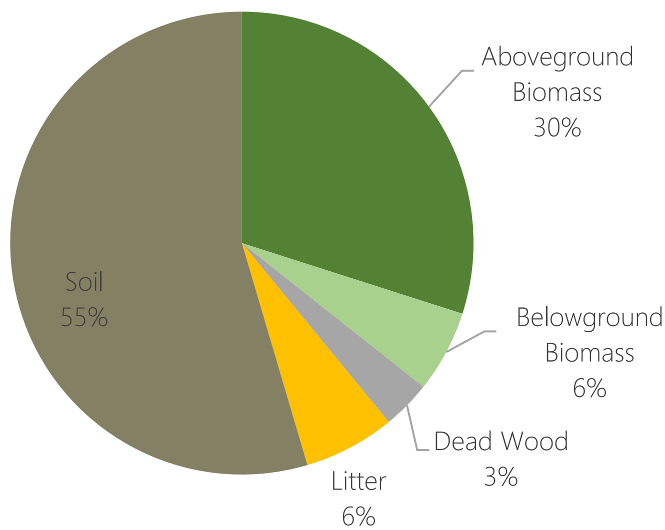
What are forest carbon pools?

Carbon is constantly in flux in a forest. As new atmospheric CO_2 is sequestered by trees and other plants, carbon is also transferred to other pools as live plants die or shed leaves or branches.

Carbon that is used in a tree's cells for branches, leaves, roots, and other living parts is the **live biomass carbon pool.** The carbon is stored in the live biomass pool until it is transferred to another pool or removed (burned, harvested, or consumed by an insect or fungi). Live roots also exude carbon directly into the soil to increase microbial processes and nutrient availability. When branches break, leaves are shed, or a tree dies, the carbon is transferred to the **dead wood carbon pool** or **leaf litter carbon pool**. As these pools are decomposed by fungi, insects, and other organisms, they release CO_2 back to the atmosphere, but some carbon is transferred to the **soil carbon pool** where it can reside for a long, if variable, time – up to centuries or millennia. Carbon in the soil can eventually make its way into rivers and lakes.

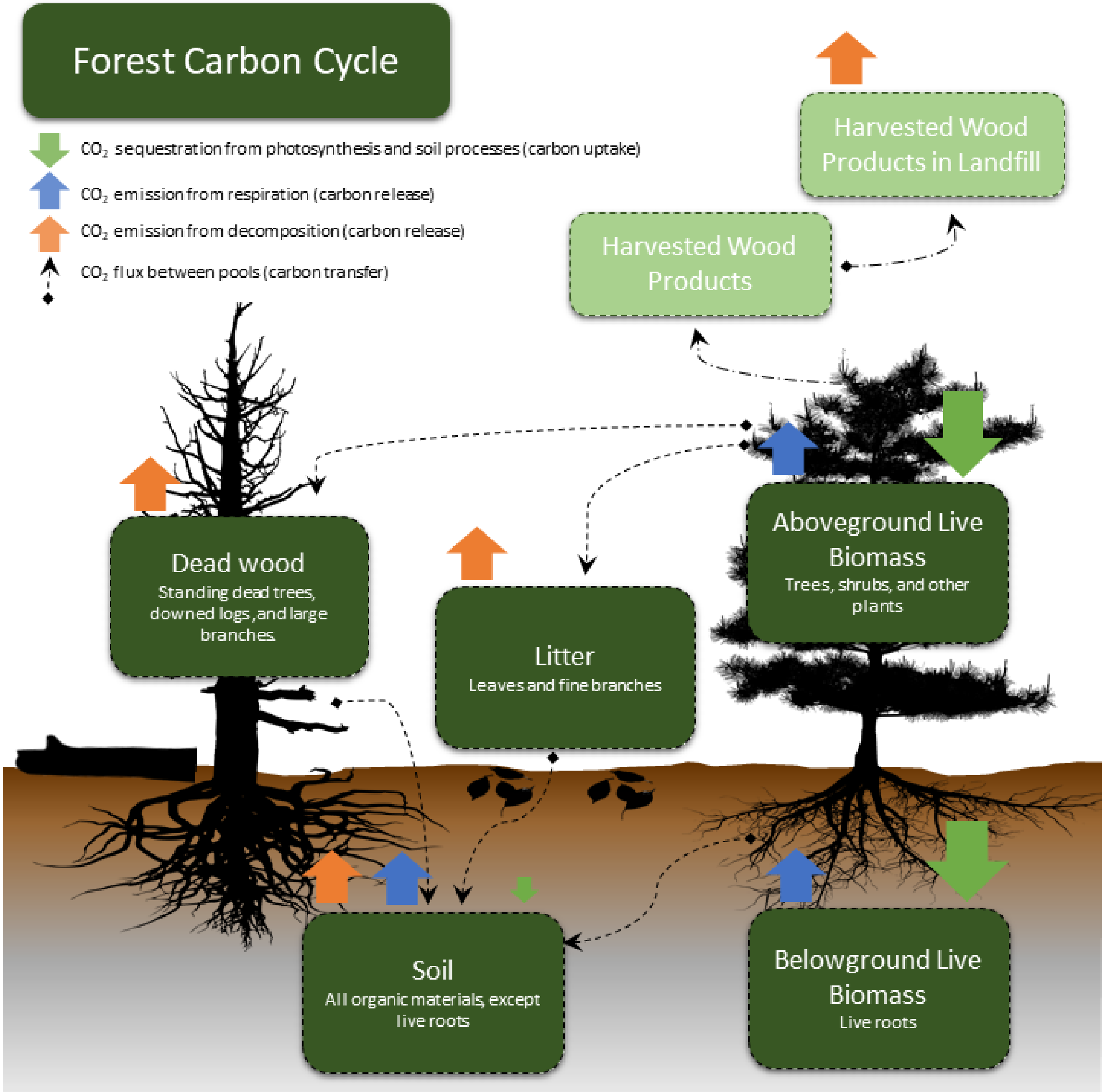
The live biomass carbon pool can be divided into aboveground (trunk, branches, leaves, bark) and belowground (roots) portions. The live biomass pool is the most dynamic of the five carbon pools, meaning that it fluctuates the most from year to year due to weather conditions and the length of the growing season. However, trees do not make up the largest carbon pool in the forest; the soil pool contains about 1.5 times more carbon than the live biomass pool[17].

For managed forests, there are also non-forest carbon pools: the **harvested wood products carbon pool** and the **harvested wood products in soil waste disposal sites carbon pool**. Carbon stored in durable wood products in furniture, cabinets, floors, and buildings may be secured for decades or even centuries – as long as the product is in use. Other wood products, like paper or cardboard, also store carbon, but for shorter periods. The landfill carbon pool accounts for the end of life of wood products that release CO_2 as they decompose.



Proportion of carbon in each of Vermont's forest carbon pools[1]

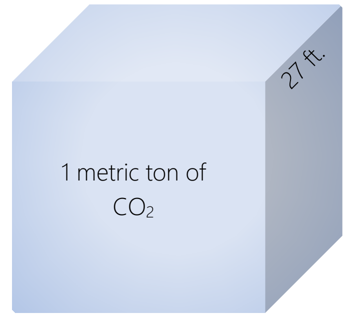
[17] Domke GM, Walters, BF, Nowak, DJ, Smith, J, Ogle, SM, Coulston, JW and Wirth, TC. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station. 227:1-5. https://doi.org/10.2737/FS-RU-227.



In forests carbon is constantly in flux moving in and out of the **five carbon pools** and the atmosphere. Carbon dioxide (CO_2) is **sequestered** by live plants through photosynthesis (green arrow; soils can also sequester CO_2, but much less). Trees store carbon as they grow branches, leaves, and roots, adding to the **live biomass pool**. As tree parts are shed or die, the carbon is transferred to the **litter pool** or **dead wood pool**. As the leaves, branches, and roots are decomposed by microbes, insects, and fungi, CO_2 is released back to the atmosphere, but some carbon is transferred to the **soil pool** where it can reside for a long time. In managed forests, carbon can also be stored in the **harvested wood products pool** and **harvested wood products in landfill pool**. Once wood products begin to decompose, they release CO_2.

What is the difference between carbon and carbon dioxide?

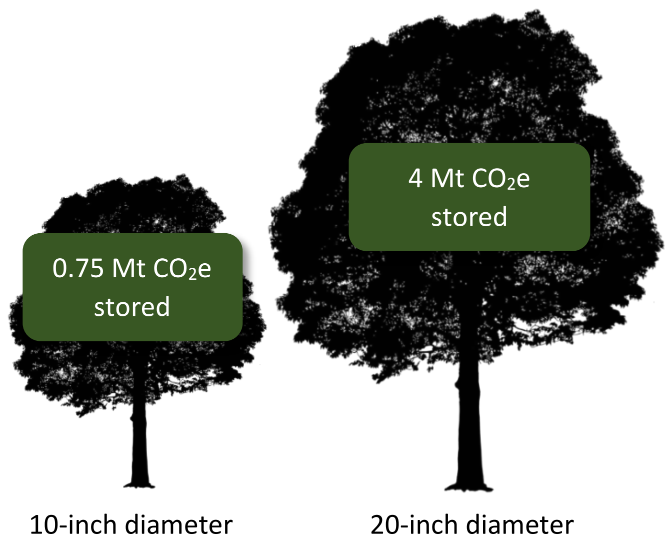
When a tree releases stored carbon through respiration, decomposition, or combustion, the carbon rejoins oxygen to make carbon dioxide (CO_2), which is released back to the atmosphere. Converting the carbon in a tree to the equivalent amount of CO_2 makes it easier to compare greenhouse gas mitigation strategies[18]. Therefore, forest carbon is usually expressed as **carbon dioxide equivalent (CO_2e)**. To convert carbon to CO_2e, multiply the amount of carbon by 3.67. This is because a molecule of CO_2 is 3.67 times heavier than a single carbon atom.



The common unit for CO_2 is a **metric ton** (Mt; also called a 'tonne'; about 2,205 lbs). One metric ton of CO_2 can be visualized as a cube measuring 27 feet on all sides[19] (about 729 cubic yards). This is equivalent to the amount of CO_2 the average Vermonter emits through day-to-day activities over three weeks[20]. For large quantities, CO_2 may be expressed as a million metric tons (MMt).

Because trees take in CO_2 but use the carbon to make wood, wood stores more than its weight in equivalent CO_2: 1 Mt of dry wood is equal to 0.5 Mt of carbon because dry wood is about 50% carbon. Because the CO_2 molecule is heavier than a carbon atom, this is equivalent to 1.8 Mt CO_2 that was taken out of the atmosphere by the growing tree.

How much CO_2 does an individual tree sequester and store?



A single sugar maple tree with a trunk 10 inches in diameter stores about 0.75 Mt CO_2e. If this tree grows a quarter of an inch in diameter (to 10¼ inches in diameter), it takes in an additional 0.04 Mt CO_2e[21]. This is roughly equivalent to amount of CO_2e emitted by driving a car about 100 miles[22]. In comparison, a 20-inch diameter sugar maple stores 4 Mt CO_2e, or about five times more carbon than the smaller sugar maple. As trees are three-dimensional in shape, the doubling of a tree's diameter results in a much larger increase in the tree's total size. The larger tree has more wood volume in the trunk, bark, branches, and roots. If the 20-inch tree also grows a quarter of an inch, it takes in an additional 0.1 Mt CO_2e -- more than twice the amount of the smaller tree. Because a tree must continually add wood to an ever-increasing volume, as a tree grows larger in size it usually does not put on the same amount of diameter growth as it did when it was smaller. Usually, the amount of

[18] For more information on carbon offset markets and credits see *Forest Carbon Markets* (Kosiba, 2020).

[19] United Nations. 2009. Press Conference on 'CO2 Cubes – Visualize a Tonne of Change. https://www.un.org/press/en/2009/091201_Cubes.doc.htm

[20] Vermont Agency of Natural Resources, Air Quality and Climate Division. 2020. Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990 – 2016. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_and_Forecast_1990-2016.pdf

[21] Using Jenkins et al. 2003 allometric equations for sugar maple above- and below- ground biomass.

[22] Assuming 20 lbs CO_2e emitted per gallon and 25 MPG.

diameter growth decreases as the tree gets larger. If the 20-inch sugar maple only grows a tenth of an inch in diameter, it would take in the same amount of CO_2e as the smaller tree did by growing a quarter of an inch.

In a forest, things are more complex: a few small trees can occupy the same amount of space as one large tree and young trees usually have the most vigorous growth because there is fierce competition for sunlight and other resources. When we consider the amount of carbon per acre of forest, the density, diversity, arrangement, and health of the trees are important.

For the average Vermonter who emits 15.6 Mt CO_2e per year[23], it would take about 12 acres of forest to remove this amount of CO_2e from the atmosphere.

How do you measure carbon in a forest?

It is very difficult to measure the amount of carbon in a tree or a forest. Instead, we estimate the amount of carbon using inventory data and established equations based on real samples. Scientists weighed parts of trees to derive species-specific equations that are based on a set ratio between a tree's diameter, height, and weight. We can easily estimate the carbon content from the weight because a tree is about 50% carbon. For rotten trees, dead trees, or dead wood on the ground, we also factor in the amount of decay because as a tree decomposes, it loses carbon – emitted back to the atmosphere through decomposition or added to the soil carbon pool. Soils are the hardest carbon pool to estimate because soil is highly variable even over a small area. Plus, soils can range from a few inches to many feet in depth. Soil carbon is usually estimated from samples that are burned in a laboratory where the emitted carbon can be captured and measured.

How much CO_2 does a forest sequester and store?

It is difficult to accurately estimate the amount of carbon stored in and sequestered by a forest, particularly the amount of soil carbon because it varies considerably from one location to the next. Based on estimates from long-term inventory plots, an acre of Vermont's forest stores about 300-400 Mt CO_2e and sequesters an additional metric ton each year[24].

However, the amount of carbon that forests store and sequester is dependent on many factors, including:

- Tree species composition
- Tree density
- Tree condition and age
- Availability of water and nutrients
- Weather events
- Climate
- Growing season length
- Soil type and depth
- Proportion of dead standing and downed trees
- Presence of earthworms

[23] Vermont Agency of Natural Resources, Air Quality and Climate Division. 2020. Vermont Greenhouse Gas Emissions Inventory and Forecast: 1990 – 2016. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_and_Forecast_1990-2016.pdf

[24] Refer to the *Vermont Forest Carbon Inventory* (Kosiba, 2020) for more specific values and analysis.

- Animal browse pressure
- History of disturbance (wind, ice, logging, insects, and disease)

Which forest types store the most carbon?

While an individual hardwood tree generally stores more carbon than a softwood (conifer) tree because it has denser wood, forests that contain conifers usually store more carbon overall (across the five carbon pools). This is because conifer needles take a long time to decompose on the forest floor, leading to a buildup of carbon in the litter and soil pools. Generally, forests that have many different species and sizes of trees, along with a deep litter layer, undisturbed soils, and lots of dead wood, have more carbon. Forests in colder climates also contain more carbon in soil and dead wood because of slower decomposition rates compared to warmer locations.

How does forest management affect carbon?

Harvesting trees for lumber, veneer, firewood, chips, or pulp removes carbon from the forest, but as long as the forest is allowed to remain a forest, other trees will quickly occupy the newly created space and sequester carbon from the atmosphere as they grow, sometimes at an accelerated rate. Creating gaps in the forest emulates natural processes and allows young trees to have sufficient sunlight and space to grow. If harvested wood is used for long-lived products, like lumber for buildings, furniture, or flooring, the carbon remains in the product for its life. There are many houses in Vermont that contain carbon that was sequestered by trees hundreds of years ago. Additional carbon benefits can come from using wood products as a substitute for concrete, steel, or fossil fuels, thus avoiding emissions from the transport and manufacture of these high-intensity products. Forest management can also help move carbon from living biomass to the dead wood, litter, and soil pools. Dead wood is particularly important in water and nutrient cycling and providing food and habitat for insects, mushrooms, and wildlife.

Additional Resources

Catanzaro P and D’Amato A. 2019. Forest Carbon: an essential natural solution for climate change. https://masswoods.org/sites/masswoods.org/files/Forest-Carbon-web_1.pdf

Catanzaro P, Ontl T, and Hagenbuch S. Forest Carbon Management and Climate Adaptation. December 11, 2019. https://youtu.be/cMZ1IDNJp5A

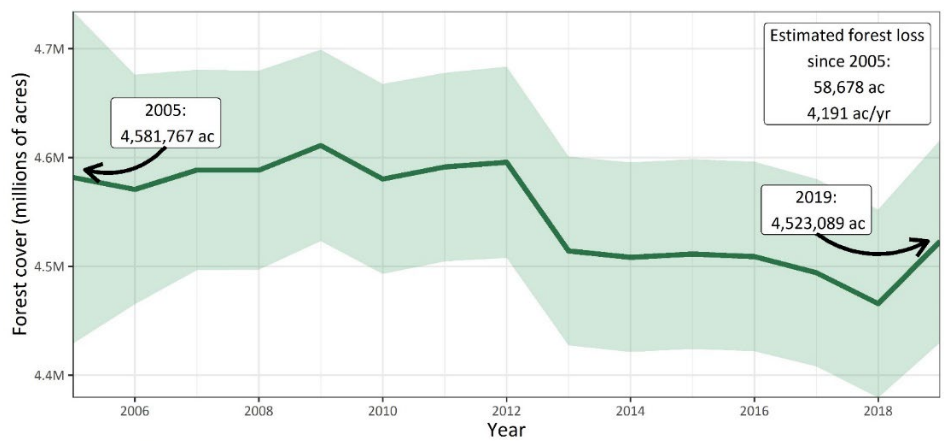
Appendix 2: Vermont Forest Carbon Inventory

Vermont Forest Carbon Inventory

Quantifying the amount of carbon contained in Vermont's forests, along with the fluxes between carbon pools over time and the impacts of human intervention (land-use conversion, harvested wood products), is necessary for maintaining the natural greenhouse gas mitigation potential of forests. Continued monitoring is essential: the impacts of climate change, coupled with other stressors, could alter forest carbon dynamics through changes in tree health and forest cycling rates. Estimates of forest cover, carbon, and land-use change were derived from the USFS Forest Inventory and Analysis program[25][26] and follow guidelines by the Intergovernmental Panel on Climate Change (IPCC 2006)[27]. More information about forest carbon, a description of pools, and definitions of terms can be found in *What is Forest Carbon?*[28]

The amount of forestland is the most important factor in determining Vermont's forest carbon.

Based on data from multiple sources, Vermont has been losing forestland to other land uses since the early 1990s. Data from the USFS FIA Program[1] estimate the loss to be 4,191 acres per year (2005-2019) and NOAA's C-CAP[29] estimate the loss to be 2,051 acres per year (1996-2016). Despite uncertainty in the amount lost, as Vermont loses any amount of forestland, statewide carbon storage and sequestration decline.



Estimated Vermont forest cover (shown in millions of acres) between 2005 and 2019 according to the USDA Forest Inventory and Analysis program (solid green line). Data were derived from forest inventory plots sampled on a rotating basis and extrapolated to the state; a complete inventory of all plots occurs every 5-7 years. Green shading shows the upper and lower uncertainty around the estimated forest area (95% confidence that the actual amount of forestland is within the green area). Even with this high amount of uncertainty, these data strongly suggest that forest cover has declined statewide.

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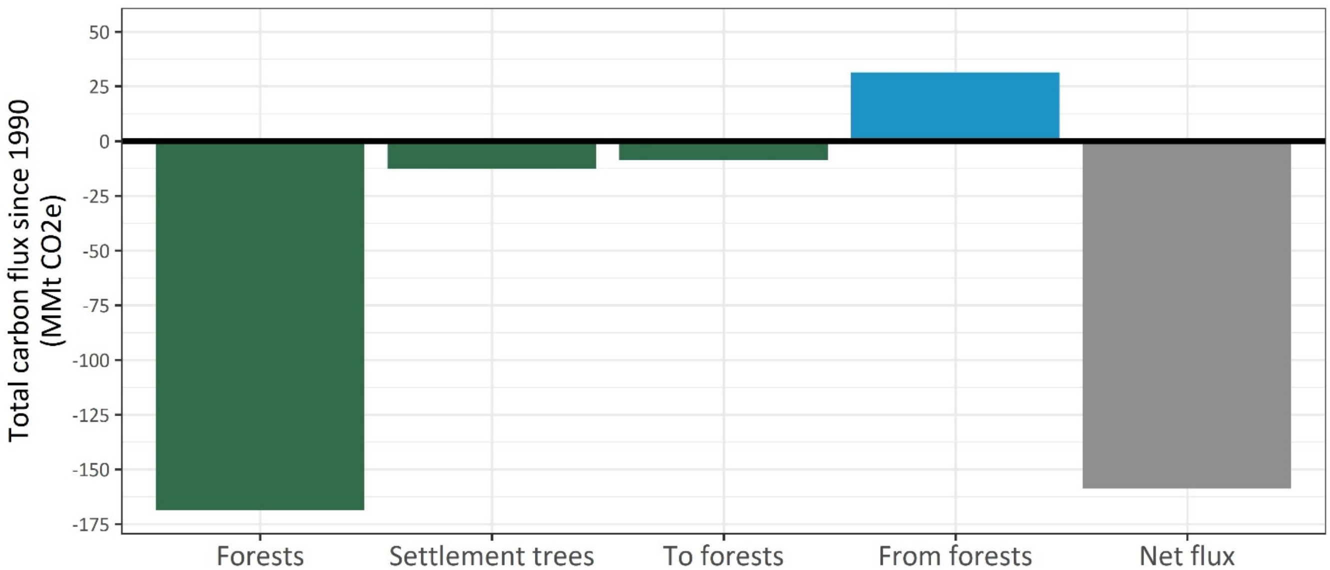
[25] USDA Forest Service. 2020. Forest Inventory and Analysis (FIA) National Program. https://www.fia.fs.fed.us/tools-data/
[26] Domke GM, Walters, BF, Nowak, DJ, Smith, J, Ogle, SM, Coulston, JW and Wirth, TC. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station. 227:1-5. https://doi.org/10.2737/FS-RU-227.
[27] IPCC. 2006. Guidelines for National Greenhouse Gas Inventories.
[28] Kosiba AM. 2020. What is Forest Carbon? Vermont Department of Forests, Parks and Recreation.
[29] NOAA. 2019. Coastal Change Analysis Program (C-CAP). https://coast.noaa.gov/ccapatlas/

Loss of Vermont's forestland has resulted in carbon emissions, but overall forests remain a carbon sink.

Since 1990, Vermont's forests that have remained forests sequestered more CO_2 than they emitted through respiration, decomposition, and disturbance -- about -168.7[30] MMt CO_2e[31][32]. In this same period, trees in towns and public areas took in an additional -12.7 MMt CO_2e. The gain of forestland was a net sink (-8.7 MMt CO_2e since 1990), but the loss of forestland to other land uses was a net source of CO_2 to the atmosphere (+31.3 MMt CO_2e since 1990). When combined across all land uses, the net carbon flux of forests remains negative, totaling over -159 MMt CO_2e taken in since 1990, or about -5.5 MMt CO_2e per year. Reducing the amount of forest land converted to other uses will help preserve this carbon sink. Note that this analysis does not include carbon sequestration by other land types, like wetlands or agriculture.



Estimated total carbon flux between 1990 and 2018 by land-use type. Carbon is expressed as a million metric tons of carbon dioxide equivalent (MMt CO_2e); negative values indicate negative emissions (net carbon uptake; green bars) and positive values indicate positive emissions (net carbon release; blue bar). Land use types are (1) forests that remained forests ('forests'), (2) settlement trees, (3) land converted to forests ('to forests'), and (4) land converted from forests ('from forests'). 'Settlement trees' are trees in developed land, including transportation infrastructure and human settlements of any size (IPCC 2006). The net flux of these four land-use types is shown in grey. Estimates were extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program and greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (IPCC 2006).

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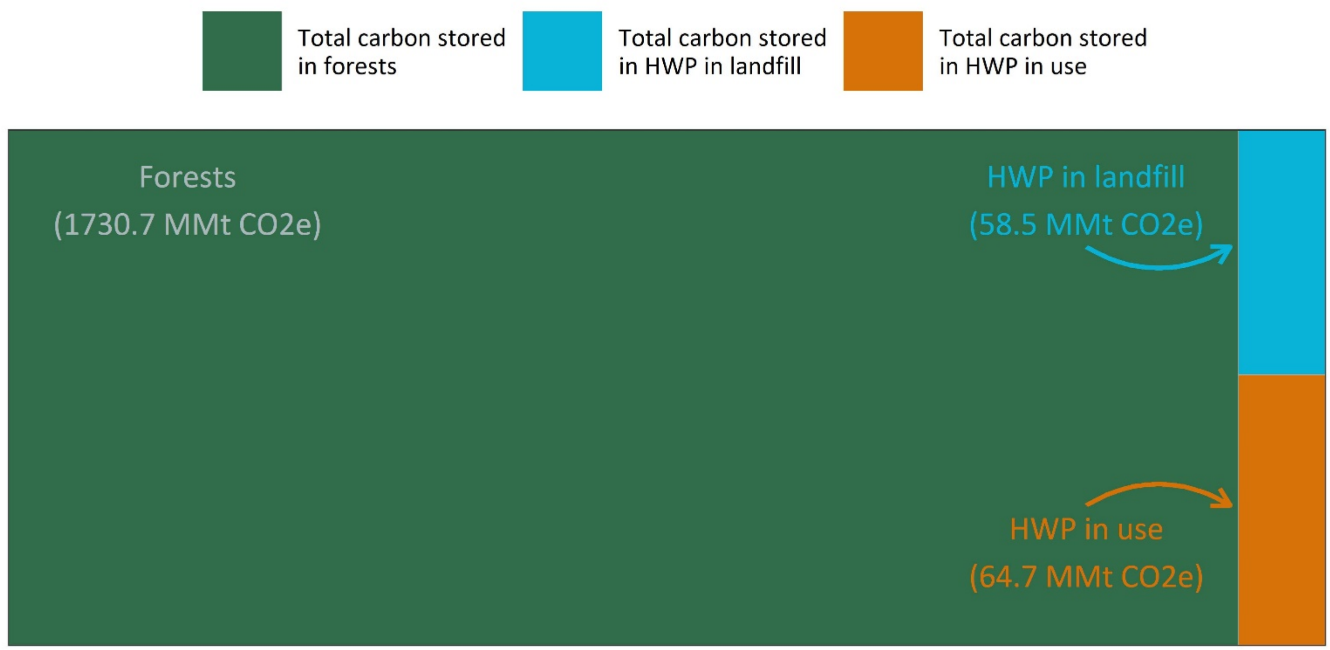
[30] Negative carbon sequestration values indicate carbon uptake, while positive values indicate emissions. For a more detailed description of forest carbon see *What is Forest Carbon?* (FPR, 2020).

[31] MMt CO_2e = Million metric tons of carbon dioxide equivalent.

[32] Domke GM, Walters, BF, Nowak, DJ, Smith, J, Ogle, SM, Coulston, JW and Wirth, TC. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station. 227:1-5. https://doi.org/10.2737/FS-RU-227.

Vermont's forests stored over 1.7 billion metric tons of CO_2e in 2018. Harvested wood products (HWP), both in use and in landfill, contributed an additional 1.2 million Mt CO_2e in carbon storage.

Vermont's forest store the equivalent of 200 years of current state annual CO_2 emissions[33]. Carbon harvested from the forest in the form of sawlogs, pulpwood, chips, and roundwood is not immediately released into the atmosphere. About a third of wood harvested in Vermont is for durable products, like floors and furniture, which store carbon for the life of the product. When harvested wood products (HWP) reach the end of their life, they continue to store carbon as they slowly decay in landfills. The amount of carbon stored in HWP both in use and in landfill has been accumulating over time, acting as a net sink of atmospheric CO_2. Locally harvested wood products support the Vermont economy and can displace other sources of emissions if they are used as a substitute for higher emissions products, like concrete, steel, or fossil fuels. Unlike land-use conversion, sustainable forest management allows remaining trees to continue to capture and store carbon.

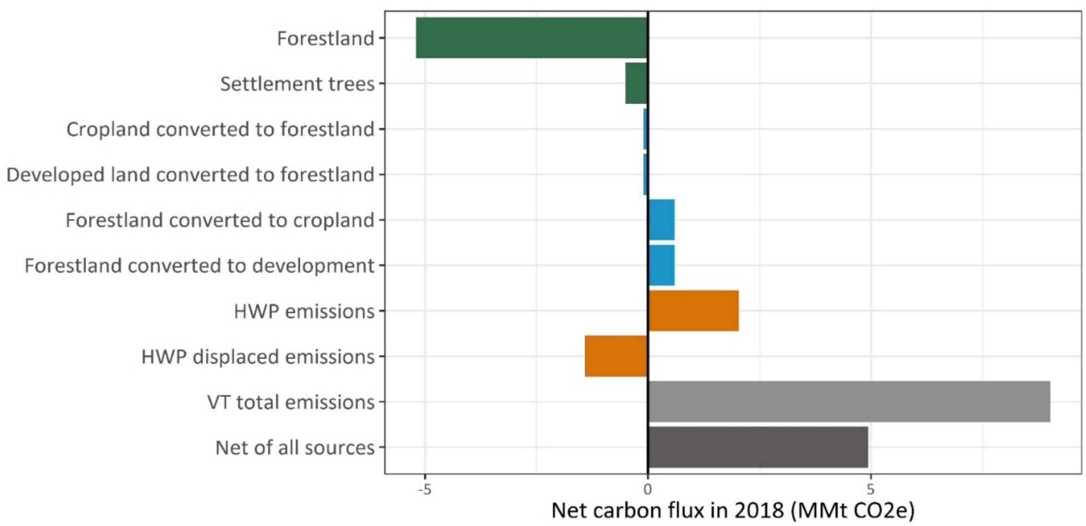


Estimated total carbon storage in Vermont's forests (sum of all five carbon pools; green) and carbon stored in harvested wood products (HWP) both in use and in landfill. All data are for 2018. Carbon is expressed as million metric tons of carbon dioxide equivalent (MMt CO_2e). Harvest data only capture aboveground carbon removed and not fluxes between carbon pools that may accompany management. Forest carbon storage was extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program and greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (2006). HWP estimates were extracted from Dugan et al. 2020 who modeled HWP emissions based on harvest reports provided by the Vermont Department of Forests, Parks and Recreation using the Carbon Budget Model.

[33] Current state level emissions are about 8-10 MMt CO_2e per year. Refer to Vermont Agency of Natural Resources. 2020. Vermont Greenhouse Gas Emissions Inventory and Forecast: Brief, 1990-2016. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_and_Forecast_1990-2016.pdf

Across all carbon sinks and sources, Vermont's forest sector took in about 45% of state annual emissions in 2018[34].

Vermont's forest sector has both sinks and sources of atmospheric CO_2. In 2018, forests sequestered about -5.2 MMt CO_2e, with trees in towns and public areas contributing an additional -0.5 MMt CO_2e. There were both lands converted to forests (net sinks) and land converted from forests (net sources) in 2018. Combined land-use changes resulted in net emissions of +1 MMt CO_2e. Importantly, land converted from forest not only emits stored carbon, but it also reduces the strength of Vermont's future forest carbon sequestration. Harvested wood products emitted +2.1 MMt CO_2e from the burning of bioenergy and decay of retired products but displaced -1.5 MMt CO_2e in emissions from the harvest and use of durable wood products and substitution of higher emissions products like steel, concrete, and fossil fuels. Comparing the total forest sector flux to the statewide total greenhouse gas (GHG) emissions, estimated to be about +9 MMT CO_2e for 2018[35], the remainder is +4.9 MMt CO_2e. In other words, the forest sequestered about half of the state's annual emissions. Reducing Vermont's GHG emissions coupled with maintaining intact, healthy, and productive forests will help us preserve forests as a natural climate solution.



Estimated forest sector carbon flux in 2018 expressed as a million metric tons of carbon dioxide equivalent (MMt CO_2e): negative values indicate negative emissions (net carbon uptake) and positive values indicate positive emissions (net carbon release). Net carbon flux by forests and settlement trees is shown in green. 'Settlement trees' are trees in developed land, including transportation infrastructure and human settlements of any size (IPCC 2006). Land converted to and from forest is shown in blue. Harvested wood product (HWP) emissions from bioenergy combustion and decay in landfills and displaced emissions from the use of durable wood products and substitution benefits are shown in orange. Statewide total greenhouse gas emissions estimated for 2018 are shown in light grey with the net flux across all sources in dark grey. Estimates of fluxes from forests, settlement trees, and land-use conversion were extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program and greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (IPCC 2006). Harvested wood product estimates were extracted from Dugan et al. 2020 who used Vermont timber harvest data to model emissions from harvested wood products. Vermont statewide emissions were extracted from the Vermont Greenhouse Gas Emissions Inventory and Forecast (Vermont Agency of Natural Resources, 2020).

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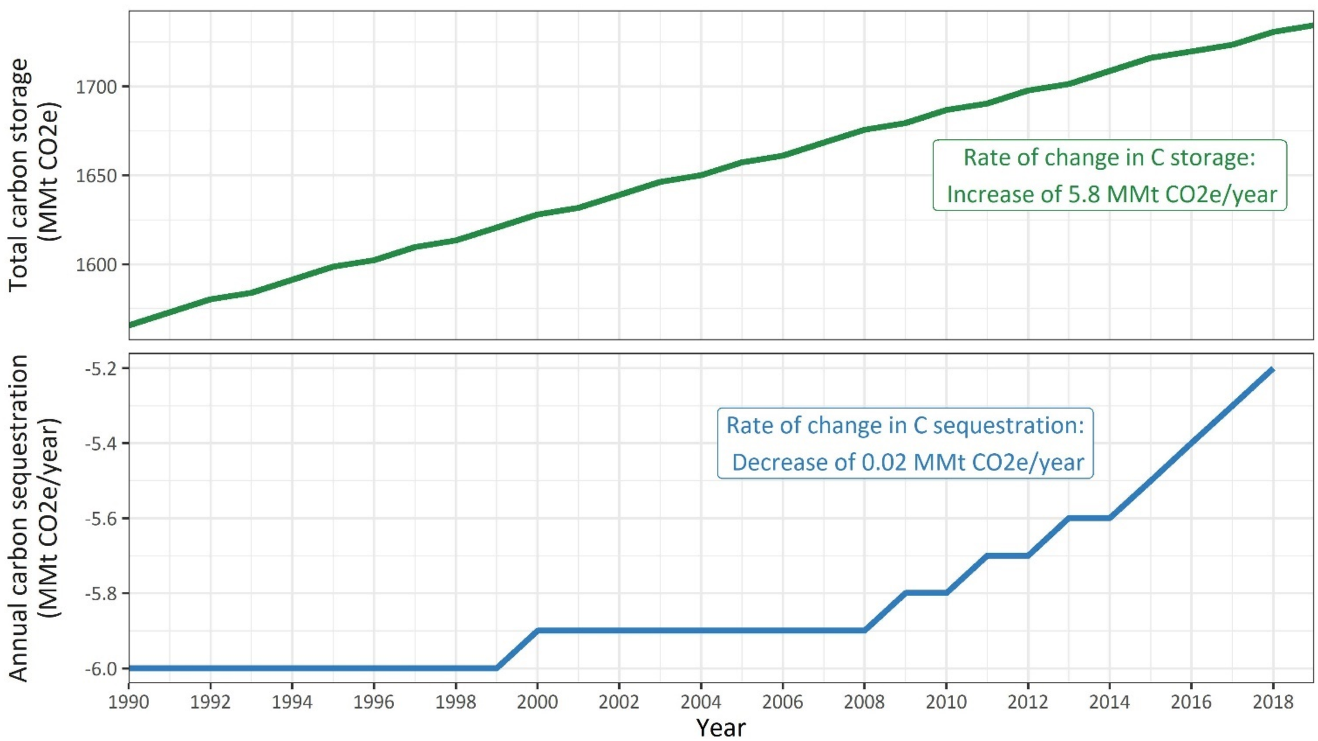
[34] Note that the forest sector sinks and sources are estimates and not included in the state GHG inventory.

[35] Vermont Agency of Natural Resources. 2020. Vermont Greenhouse Gas Emissions Inventory and Forecast: Brief, 1990-2016. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_and_Forecast_1990-2016.pdf

For forests that have remained forests, the amount of carbon storage has increased over time, but the annual rate of carbon sequestration has decreased.

In 2019, Vermont's forests stored an estimated 1,734 MMt CO_2e[36]. Since 1990, storage has increased by 168.7 MMt CO_2e, but the rate of carbon uptake by forests has slowed over time. In the early 1990s, forests sequestered -6.0 MMt CO_2e per year, but in 2019, the rate declined to -5.2 MMt CO_2e, meaning that Vermont's forests are storing carbon at a slower rate than they did two decades ago. This decline is likely because of our similarly aged and aging trees. While older forests store much more carbon than younger trees, they sequester carbon at a slower rate. Another factor may be due to climate change: higher air temperatures can speed up the rate of nutrient cycling in a forest.

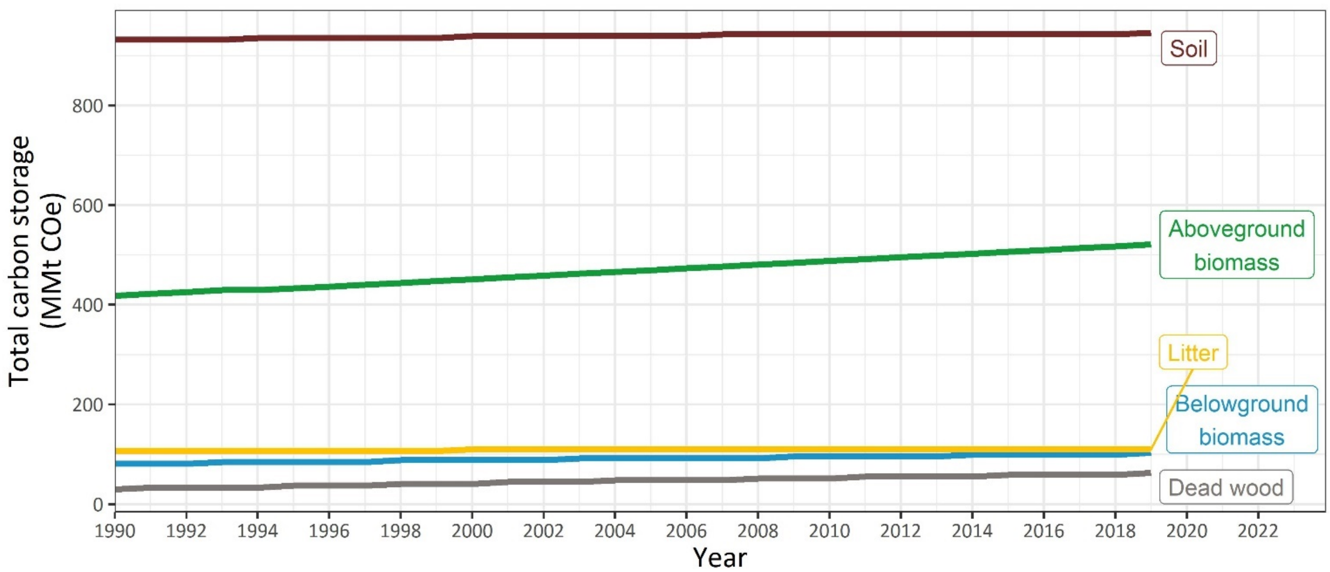


Estimated total carbon storage and net annual carbon sequestration for forests that have remained forests in Vermont between 1990 and 2019. Carbon is expressed as a million metric tons of carbon dioxide equivalent (MMt CO_2e). For sequestration, negative values indicate negative emissions (net carbon uptake). Estimates were extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program and greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (2006). These data suggest that while the total carbon storage of Vermont's forests has increased, the amount of carbon sequestered each year has decreased.

[36] To convert from carbon dioxide equivalent (CO_2e) to carbon, divide by 3.67.

For forests that have remained forests, carbon stored in the five carbon pools has increased or remained stable; the largest increase has occurred in the live biomass pool.

Across Vermont's forestland, carbon storage in each of the five forest carbon pools[37] has increased since 1990. Soils store more than half of the carbon in the forest: 946 MMt CO_2e compared to 796 MMt CO_2e for the four other pools combined. The live biomass carbon pool is the most dynamic of the carbon pools and has increased at the fastest rate. As a tree grows larger, it stores more carbon. While carbon is constantly relocating from the live biomass pool to the other carbon pools, this process is slow; natural disturbances, tree mortality, and forest management are required to see quicker increases in the other carbon pools.

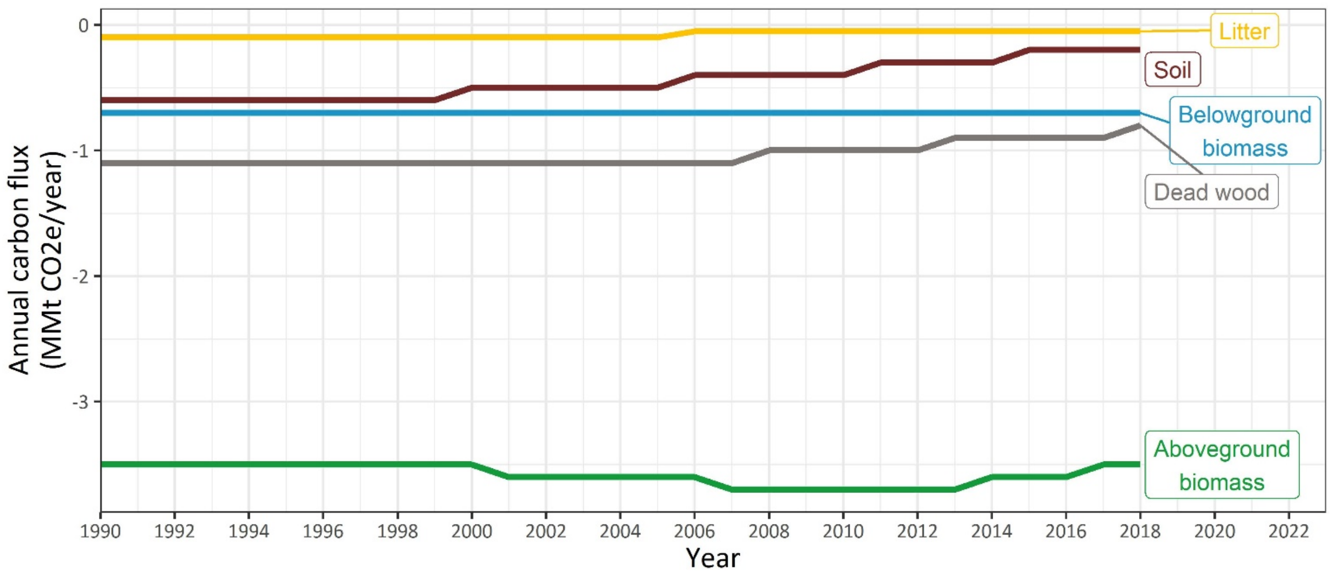


Estimated total carbon storage for forests that have remained forests in Vermont, shown by carbon pool and year. Carbon is expressed as a million metric tons of carbon dioxide equivalent (MMt CO_2e). The five carbon pools are (1)soil (1 m depth), (2) aboveground biomass (live trees and shrubs), (3) litter (leaves, needles, twigs), (4) belowground biomass (roots of live biomass > 2 mm diameter), and (5) dead wood (standing dead trees, downed logs and branches). Estimates were extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program and greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (2006). Data suggest that Vermont's forest carbon stocks have increased over time, primarily due to increased carbon stored in live biomass.

[37] For more information on forest carbon pools refer to What is Forest Carbon? (Kosiba AM, 2020).

For forests that have remained forests, the flux rate of the five carbon pools has remained a net carbon sink, but the dead wood, litter, and soil carbon pools show reduced carbon uptake over time.

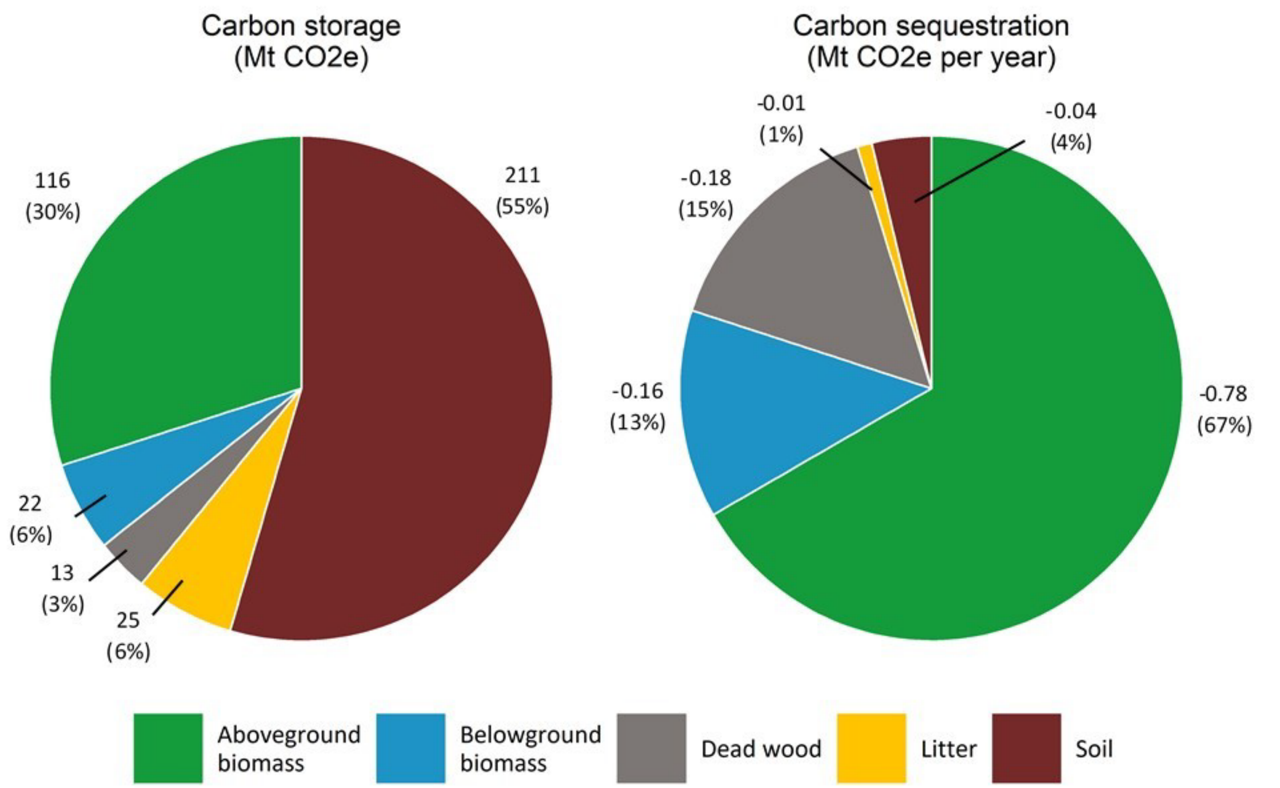
Since 1990, all five of the forest carbon pools have remained a carbon sink, meaning that they sequestered more CO_2 than they emitted through respiration, decomposition, and disturbance. The live aboveground biomass pool sequestered twice the amount of CO_2 as the other four pools combined (-3.50 MMt CO_2e compared to -1.75 MMt CO_2e). The dead wood, litter, and soil pools show a worrisome slowing rate of carbon uptake over time. These changes may be due to warmer air temperatures that have occurred because of climate change. Warmer air temperatures can increase the rate of decomposition in a forest. This decline in the uptake of soils, litter, and dead wood pools also suggests that increased storage in live biomass is not being transferred into the dead wood, litter, and soil pools. These pools could be enlarged using management techniques designed to increase downed material, which would also increase the sequestration rate in live biomass.



Estimated annual carbon sequestration (flux) for forests that have remained forests in Vermont, shown by carbon pool and year. Carbon is expressed as a million metric tons of carbon dioxide equivalent per year (MMt CO_2e/year); negative values indicate negative emissions (net carbon uptake) and positive values indicate positive emissions (net carbon release). The five carbon pools are (1) soil (1 m depth), (2) aboveground biomass (live trees and shrubs), (3) litter (leaves, needles, twigs), (4) belowground biomass (roots of live biomass > 2 mm diameter), and (5) dead wood (standing dead trees, downed logs and branches). Estimates were extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program and greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (2006). These data suggest that the strength of Vermont's forest carbon sink has decreased over time due to the soil, litter, and dead wood pools.

On average, an acre of Vermont's forests stored 389 Mt CO_2e and sequestered an additional -1.3 Mt CO_2e in 2018, but the relative contribution to total storage and sequestration varied by carbon pool.

In an average acre of Vermont's forests, soils store more than half of the total carbon. The live biomass pool (a combination of the above- and belowground live biomass pools) makes up about 36% of the total carbon storage. In terms of the rate of carbon uptake (sequestration), the live biomass pool sequesters 80% of the carbon. Carbon sequestered by live plants is transferred to the other pools over time as trees shed parts or die. While soils are the largest pool of stored carbon in a forest, they accrue carbon much more slowly than other pools, meaning that a loss of soil carbon can take a long time to recuperate. Note that these values are the estimated average carbon per acre in Vermont; an actual acre of forest may store and sequester less or more carbon and the ratios among the pools may differ.



Estimated average forest carbon storage per acre (left) and the annual rate of carbon sequestration per acre (net flux, negative values indicate net uptake; right). Carbon data are for 2018 and expressed as metric tons of carbon dioxide equivalent (Mt CO_2e). The five carbon pools are (1) soil (1 m depth), (2) aboveground biomass (live trees and shrubs), (3) litter (leaves, needles, twigs), (4) belowground biomass (roots of live biomass > 2 mm diameter), and (5) dead wood (standing dead trees, downed logs and branches). Estimates of carbon sequestration by forests were extracted from Domke et al. 2020 who used data collected by the USDA Forest Inventory and Analysis program.

Appendix 3: Forest Carbon Markets for Vermont Landowners

Natural climate solutions

Forests are considered a natural solution to climate change because they remove carbon dioxide (CO_2) - a potent greenhouse gas (GHG) - from the atmosphere and store the carbon in wood and soil[38]. Increasing the amount of carbon stored in forests and harvested wood products can reduce the amount of CO_2 in the atmosphere while providing the other critical ecosystem services that forests provide. New carbon offset markets allow landowners to sell the carbon taken up by their forest to another entity to compensate for emissions made elsewhere. Because of the interest in forest carbon offsets from landowners and emitters, new opportunities for selling forest carbon are rapidly developing. Forest carbon offset projects can include improved forest management practices, avoided deforestation, or tree planting. Programs are open to all forestland owners, including family forests, municipalities, tribes, non-profit groups, and public entities. Selling forest carbon can provide an additional source of revenue to a landowner and the long-term commitment keeps forests intact.

What is a carbon offset?

A **carbon offset** – also referred to as a **carbon credit –** is a reduction in GHG emissions in one location that compensates for or "offsets" GHG emissions made elsewhere. As businesses, municipalities, organizations, and individuals make efforts to reduce their GHG emissions, reductions can be difficult, costly, and take time. Carbon offsets are intended to help entities reduce their emissions by purchasing offsets where carbon is actively being sequestered or emissions avoided.

Carbon offsets represent direct emission reductions or sequestration; for example, the capture of methane emitted from decaying manure at a dairy farm or the carbon sequestration from trees planted in an abandoned quarry. Carbon offsets are also called **emission reduction tons (ERTs)** because a metric ton of CO_2 is the standard unit for carbon accounting.

While CO_2 is the most abundant GHG, emissions reductions apply to other GHGs as well **–** like methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Each GHG has a different global warming potential (GWP), which is based on how long the GHG stays in the atmosphere and how strongly it impacts the atmosphere. For simplicity, all GHGs are compared to CO_2 and expressed in the same unit: metric tons of carbon dioxide equivalent (Mt CO_2e). Carbon dioxide has a GWP of 1, while methane has a GWP of 25[39]. This means that 1 Mt of CH_4 is equivalent to 25 Mt of CO_2e.

Carbon registries & markets

Carbon offset projects and their eligibility criteria are registered and tracked through independent **carbon registries** that monitor and supervise their use, trade, and retirement. All carbon offset projects must be real, additional, verifiable, permanent, and enforceable.

[38] For background information on forest carbon, terminology, and differences between forest types see *What is Forest Carbon?* (Kosiba, 2020).

[39] Based on 100-year timeframe. Source: EPA https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

The Five Requirements of Carbon Offset Projects

Real	Reductions in emissions or increases in carbon sequestration must be tangible.
Additional	Reductions in emissions or increases in carbon sequestration must occur beyond a baseline scenario and not be the result of a prior legal commitment.
Verifiable	Reductions in emissions or increases in carbon sequestration must be quantifiable, monitorable, and verifiable by an accredited third-party through a standardized system.
Permanent	Reductions in emissions or increases in carbon sequestration must last in perpetuity (at least as long as the project contract).
Enforceable	Reductions in emissions or increases in carbon sequestration can be counted only once.

Carbon offsets are bought and sold in a **carbon market.** There are two types of carbon markets: **regulatory/compliance** and **voluntary**. The distinction between these two markets pertains only to the GHG emitter (purchaser) , not the seller of carbon offsets. In the regulatory market, there is a government mandate to reduce emissions, while in the voluntary market there is none. A key component of both types of carbon markets is the ability of regulators, buyers, brokers, and sellers to have a commodity that is measurable, quantifiable, verifiable, and trackable. To ensure these traits, carbon offsets need to comply with strict protocols or standards set by the registry. Registries have multiple standards that can be used for different types of carbon offset projects.

Regulatory/compliance carbon markets

In regulatory or compliance carbon markets, emitters of GHG are required by law to reduce their emissions but are provided the option to purchase allowances from other regulated emitters or buy offsets from carbon sequestration or emissions-reduction projects. For example, California's Cap-and-Trade program allows emitters to buy a percentage of their required emissions reductions from carbon offset projects, but the amount that emitters can offset is decreased over time. This market is overseen by the California Air Resources Board (CARB). In the Northeast, the Regional Greenhouse Gas Initiative (RGGI) cooperative market establishes regional caps on emissions from the power sector. As more governments regulate GHG emissions, we may see an expansion of regulatory markets. However, these markets are currently not well-suited for Vermont forestland owners because California's Cap-and-Trade market limits the number of offset projects that can be located outside of the state of California and RGGI is not currently used for forest carbon projects.

Voluntary carbon markets

Unlike regulatory carbon markets, voluntary carbon markets are not required by law and for this reason can lack the same level of compliance enforcement seen in California's Cap-and-Trade program, for example. The voluntary market allows individuals, companies, and other entities to purchase carbon offsets to mitigate their GHG emissions from transportation, electricity use, and other sources. Three of the most common registries in the voluntary market are the American Carbon Registry (ACR), Climate Action Reserve (CAR), Gold Standard, and Verified Carbon Standard (VCS). For forest carbon projects in the Northeast, ACR is more commonly used compared to the other registries. There are also other registries developed or in development for specific sectors, for example, City Forest Credits[40] that can be used by municipalities.

Carbon offset credits sold on the voluntary market generally follow more flexible accounting and measurement guidelines than those on the regulatory market. Carbon offset prices span a wider range than in the regulatory market and more factors affect the price, including the type and location of the project, additional project benefits, marketing, and demand. Voluntary markets also more easily allow for the aggregation of multiple parcels into a single project.

The Two Types of Carbon Markets and Their Associated Registries

Compliance/Regulatory Market	Voluntary Market
• California Air Resources Board (CARB) • Regional Greenhouse Gas Initiative (RGGI)	• American Carbon Registry (ACR) • Climate Action Reserve (CAR) • Verified Carbon Standard (VCS) • Gold Standard

Benefits of forest carbon projects

Forest carbon offset projects are open to private, industrial, tribal, and public landowners. The primary goal of carbon offsets is to help entities compensate for GHG emissions as they work to reduce those emissions. In this way, carbon markets allow for the private sector to provide financial support for forests. Enrolling forestland in a long-term carbon agreement ensures that the land remains forested for the contract period. Keeping forests intact helps to protect the other vital ecosystem services that forests provide, like water cycling, wildlife habitat, and flood resilience. The revenue earned by a landowner from selling forest carbon could be used for other goals, like land conservation, trail maintenance, timber stand improvement, invasive species control, or wildlife habitat improvements. Additionally, it is feasible that the landowner could use the generated carbon offsets to compensate for their emissions. For example, Middlebury College uses some of the credits generated from the Breadloaf Wilderness carbon project to offset campus emissions.

How do forest carbon offset projects work?

Types of forest carbon projects

Three project types are eligible to produce forest carbon credits: **afforestation** or **reforestation** (A/R), **avoided conversion** (AC), and **improved forest management** (IFM). Unless there the parcel has an imminent risk of deforestation or tree planting will be undertaken, most forestland owners in Vermont will be interested in the Improved Forest Management (IFM) category. IFM carbon projects allow for both active and passive forest management. There are a variety of forest management strategies that can be

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[40] https://www.cityforestcredits.org/about-city-forest-credits/

used to maintain or increase carbon stocks. Timber management under a carbon offset project may require lighter and less frequent harvests compared to forests where the primary objective is wood product yield.

The Three Types of Forest Carbon Projects

Afforestation/Reforestation (A/R)	Avoided Conversion (AC)	Improved Forest Management (IFM)
Carbon offsets are generated through the carbon storage of newly planted trees, either on non-forested sites (afforestation) or to reestablish forests (reforestation).	Carbon offsets are generated by preventing the conversion of forested land to non-forested land.	Carbon offsets are generated through forest management activities that increase or at a minimum maintain the current level of carbon stocking.

Key attributes of forest carbon projects

For all forest carbon projects, carbon registries outline strict requirements for eligibility. Carbon projects must demonstrate that there is additional carbon capture that would not have occurred without the carbon project, or **additionality**. Additionality is the difference between the carbon storage of the forest if it was enrolled in a carbon offset project compared to the carbon storage if it was not enrolled in a carbon project. The latter is usually called the **baseline**. The baseline is defined according to the project type and can relate to common practice, business as usual, standardized emissions estimates, profit maximization, or minimum legal requirements. The project must have a long-term commitment, or **permanence**, to ensure that the stored carbon is not immediately released. And the project must demonstrate that it does not facilitate any new GHG emissions elsewhere, or **leakage**. For example, there are penalties if the carbon project results in an increase in timber harvesting in another location. The number of carbon credits that a project produces is based on the additionality while accounting for permanence and leakage.

The Three Key Attributes of Forest Carbon Projects

Additionality

The difference between the project scenario and the baseline is called additionality and is the basis for the carbon offsets generated from the project. Additional carbon stored is verified periodically.

Permanence

Projects must contribute a proportion of generated offets to a buffer pool based on the risk of unintentional reversal due to a natural disturbance. The risk is computed based on forest type, location, and other site factors.

Leakage

Leakage happens if project reduces timber harvest volumes compared to the baseline, which could result in increased harvesting elsewhere to meet wood market demands.

The project must demonstrate that it does not cause excessive leakage, or if it does, must compensate for leakage in offsets credited.

Forest carbon project compatibility with other programs

Forestlands enrolled in a forest carbon offset project can be actively managed for timber and other wood products along with additional goals like improved wildlife habitat or recreational opportunities. In general, forest carbon offset projects are compatible with other forest programs if they do not restrict timber harvests or mandate carbon storage.

Use Value Appraisal program

Forests enrolled in Vermont's Use Value Appraisal (UVA) program (the current use tax equity program) are eligible for enrollment in a carbon offset market. A key criterion of the UVA program is that the parcel has an up-to-date and active forest management plan prepared by a VT licensed forester and approved by a Vermont Forests, Parks and Recreation County Forester. The pre-existence of a UVA management plan can help determine eligibility and expedite the carbon offset project development process. If the land continues to be actively managed under a carbon offset project, selling carbon will not invalidate the UVA program criteria. Keep in mind that if the UVA forest management plan needs adjustment because of enrollment in a carbon project, an amendment will need to be approved by VT FPR. Also of importance to note is that If changes were to be considered in the UVA program, the State should avoid program requirements that may constrain carbon offset project viability for lands enrolled in UVA.

Conservation easements

Having a conservation easement on forestland, like through a local land trust or government organization, should not restrict eligibility in a carbon offset project. The exceptions would be if the easement specifically mandates that the landowner maximize forest carbon or restricts timber harvest. In these cases, future carbon capture is already accounted for to meet the legal agreement of the easement and the landowner cannot sell the forest carbon a second time. For some projects, having a conservation easement can lower the risk associated with the project, which can increase the number of offsets credited. The Forest Legacy Program (FLP), a federal program that provides funding to states to conserve private land with unique or important forest characteristics and environmental value, is compatible with carbon markets, conservation easements, forest certification, and Vermont's UVA program, and the program requires a management plan.

Cost-share programs

The Environmental Quality Incentives Program (EQIP), administered by the Natural Resources Conservation Service (NRCS), can provide financial and technical assistance to landowners for forest management planning and silviculture, including forestland enrolled in a carbon offset program.

Third-party forest certification

Forest certification programs ensure that forestland owners use sustainable forest management practices. All three types of forest certifications – Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC), and American Tree Farm System (ATFS) – are compatible with carbon offset markets.

Forest carbon options for small forests

Currently, many challenges exist for owners of small forest parcels to sell forest carbon. Upfront project development costs can be large and therefore challenging when not spread over many acres of ownership, and the process is complex. Under current protocols and market prices for carbon offsets, projects need to encompass more than 2000 acres to be financially viable, although this is not a technical or legal requirement per se. As carbon markets evolve, the cost of development may decrease and the sale price of a carbon offset may increase such that the size threshold for financial feasibility declines.

While current markets favor large forest parcels, the voluntary market is rapidly developing, and new options are becoming available. One option for smaller landowners is to aggregate smaller forest parcels into a single carbon offset project. Because there are more landowners involved in an aggregation project, it can introduce additional complexities and risks. While some carbon registries have guidelines for aggregating forest carbon projects, successful aggregated projects are not yet common. There is one example of project aggregation in Vermont: the Cold Hollow to Canada Carbon Project, a forest carbon offset aggregation project of 10 landowners[41]. As there is growing interest in enrolling land in a carbon offset project, coordinated efforts to provide financial and technical assistance to small forest owners will likely increase.

There are also other pathways for smaller private forests to enter carbon markets that seek to lower development and inventory costs.

- The Family Forest Carbon Program[42]
  A joint program between The Nature Conservancy and American Forest Foundation that reduces development costs by using national forest inventory data and a payment-for-practice incentive. The minimum parcel size is 50 acres. Currently, this program is being piloted in Pennsylvania and Western Massachusetts/Southern Vermont.
- Core Carbon[43]
  A new program by carbon developer Finite Carbon is designed for family forests as small as 40 acres. This program will be released in 2021.

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41 https://vlt.org/forests-wildlife-nature/local-solution-global-impact-forest-carbon
42 https://www.nature.org/en-us/what-we-do/our-insights/perspectives/family-forests-powerhouse-in-climate-mitigation/
43 https://corecarbon.com/

In addition to these new programs for owners of small forest parcels, there is a recognized need for more standardization and transparency for carbon projects for natural and working lands, like forests and farms. Currently, there is a bipartisan bill in the US Congress, the Growing Climate Solutions Act[44], that would establish a USDA certification for carbon experts, developers, and third-party verifiers and an online marketplace for buyers and sellers. The accompanying Rural Forest Markets Act[45] would provide project funding.

The general process for developing a forest carbon project on the voluntary market

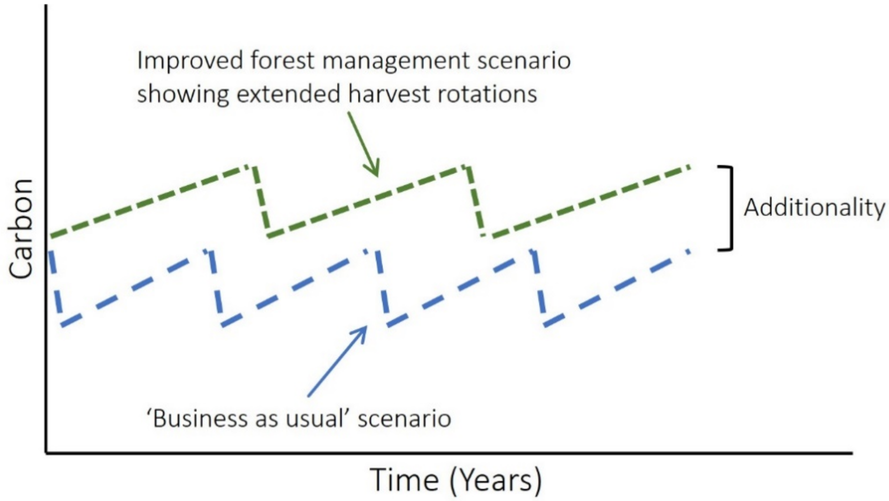
To begin a forest carbon project, the landowner typically needs to contract with a private carbon developer. The carbon project developer will work with the landowner to oversee, develop, broker, and market the carbon project, for a fee, typically as a percent of sales proceeds. For a list of current developers, refer to the table at the end of this document. Carbon project developers may develop projects for enrollment on one or more carbon registries but are independent from the registries.

The developer will determine if the land is eligible for enrollment in a carbon registry standard and financially feasible to proceed. Often this process is free, or has a nominal fee, and does not require a commitment. For the assessment, the developer will need information on the characteristics of the forest parcel, like forest type, size, and stocking. Forest parcels do not have to be contiguous to be enrolled. The developer will need information on any legal constraints on the parcel, like easements, planned management, and parcel operability that may limit harvesting. With satellite data, this assessment may be able to occur without collecting new data. Having a current active management plan can facilitate this process. If the project is eligible and financially feasible, the official project development stage begins.

The developer will conduct a sample inventory of living and dead trees to quantify carbon stocks. To compute the potential offsets generated from the project, the developer will use the inventory data to model average carbon stocks over time under the baseline scenario and the project's scenario. For improved forest management (IFM) projects under the American Carbon Registry (ACR), one of the standards commonly used computes the baseline carbon stocks using the legally acceptable harvest that could occur, per the forest and landowner type, to maximize near term revenue. The project scenario must retain more carbon on-site compared to the baseline, but that can be achieved with a variety of silvicultural strategies, like extended rotations (harvest intervals), higher retention of trees, and lower removals. The difference between the carbon stocks in the project scenario and the baseline is the additionality and the basis for the number of offsets generated. IFM projects require an active forest management plan that will describe the silvicultural prescriptions that will be implemented to achieve higher carbon stocks compared to the baseline.

[44] https://www.braun.senate.gov/sites/default/files/2020-06/Growing%20Climate%20Solutions%20Act%20One%20Pager_0.pdf
[45] https://www.agriculture.senate.gov/imo/media/doc/Rural%20Forests%20Factsheet_Final.pdf

Example of Additionality in an IFM Carbon Project
Compared to 'Business as Usual'



Projects must also include deductions for leakage. If the project will harvest fewer wood products compared to the baseline scenario, the project could result in increased timber harvesting somewhere else to meet wood market demands. Leakage is deducted from the number of offsets generated based on the amount of reduction in harvested wood products compared to the baseline. Projects must also compute the risk of unintentional reversal that could occur from a natural disturbance like an ice storm, insect outbreak, or fire. Projects must contribute a proportion of offsets generated to a buffer pool (contingency funds) based on the project-specific risk of reversal.

These calculations and assumptions must be reviewed and verified by a third-party organization, which is arranged by the project developer. Registries give each metric ton of emissions reduction a unique serial number and the offset can then be sold and once purchased, retired. Carbon stocks must be periodically re-measured and verified. This process can vary depending on the registry and standard used, and novel programs for smaller forest parcels that aim to reduce the cost of project development may differ.

Landowners can use the table below to find a project developer that matches the amount of forestland and other criteria. Carbon project developers can help determine if your property is a good fit for a carbon program. Keep in mind that many of the programs for smaller forest owners are in development; you may need to wait until they are open for enrollment.

List of Forest Carbon Offset Project Developers and Programs[46]

Developer/Program	Website	Registry standard(s)[47]	Commitment	Min. parcel size
American Forest Foundation & The Nature Conservancy – Family Forest Carbon Program[48]	https://www.familyforestcarbon.org/	VCS	20-year minimum	50-2400 acres
Blue Source	http://www.bluesource.com	ACR, VSC, CAR, ARB	40 or 100 years	>3000 acres
Finite Carbon	https://www.finitecarbon.com	ACR	40 years	>2000 acres
Finite Carbon – Core Carbon Program[4]	https://corecarbon.com	ACR	40 years	>40 acres
Forest Carbon Works	https://forestcarbonworks.org	ARB	100 years	>40 acres
Forest Carbon Partners (New Forests)	https://newforests.com.au/forests-carbon-partners	ARB	100 years	Not provided
SilviaTerra – Natural Capital Exchange (NCAPX)	https://www.silviaterra.com/ncapx	RISE[49]	1 year	>20 acres
Spatial Informatics Group (SIG)	https://sig-gis.com/carbon-offsets	ARB, CAR, VCS	40 or 100 years	Varies
Terra Carbon	http://www.terracarbon.com	ARB	100 years	Not provided
The Nature Conservancy – Family Forest Co-op[4]	https://www.nature.org/en-us/what-we-do/our-insights/perspectives/family-forests-powerhouse-in-climate-mitigation	VSC	40 years	200-2400 acres
The Nature Conservancy & Blue Source – Working Woodlands	https://www.nature.org/en-us/about-us/where-we-work/united-states/working-woodlands	VSC	40 years	>2400 acres

Frequently asked questions about forest carbon offset projects

How does a landowner enroll forestland in a carbon offset project?

A forester may be able to help you navigate forest carbon offsets, but as this is a new and rapidly changing economic sector, talking to a carbon developer will be the best way to determine if your land is eligible to be enrolled in a carbon offset market. Because there are not many forest carbon projects in the Northeast, many foresters and managers do not yet have experience in project facilitation. Refer to the table above for a current list of project developers.

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[46] As of October 2020, list is subject to change. Inclusion does not signify an endorsement by VT FPR.
[47] Refer to list of registry abbreviations in previous table.
[48] Currently in development.
[49] RISE: Real, Immediate, Scalable, and Efficient. Note that this framework varies from the other standards and is in its first year of enrollment. Refer to https://www.silviaterra.com/ncapx

Is active forest management allowed under a forest carbon project?

Under the 'Improved Forest Management' type of forest carbon projects, parcels can be actively or passively managed. Landowners will need a professional management plan describing the silvicultural strategies and prescription schedule. Forest management can have additional carbon benefits if harvested wood products are used as a substitute for fossil fuels, concrete, or steel, and long-lived, durable wood products can result in carbon storage for the life of the product.

What happens if there is a natural disturbance on the property?

Most carbon projects require that a certain number of carbon offsets to be set aside in case there is a loss of forest carbon due to a natural disturbance, like insect defoliation, fire, wind event, or ice storm. The methodology to compute the risk of natural disturbance and the number of offsets to add to this buffer pool varies by the registry. A carbon developer can provide more information.

Does it matter what kind of wood products are produced from the harvest?

The expected lifecycle of the harvested wood products can add additional carbon storage, but this does require additional accounting. Many protocols simplify this accounting and assume a single life span for all harvested wood.

Can a carbon offset contract be terminated early?

There can be a large penalty for leaving a carbon project and the landowner may be responsible for repaying the offsets generated. These details are described in a carbon project contract. Entering a carbon project does require a time commitment. Although there are new options that require shorter commitments, these programs are in development or are not yet widely vetted.

How much revenue can you earn from a forest carbon project?

The amount of revenue a landowner can make with a carbon offset project varies greatly. It depends on the market, tree stocking and condition, site factors, size of the parcel, and future timber harvests. Costs of project development, inventory, and verification can vary by project and the standard used. The new programs for smaller parcels (e.g., Family Forest Carbon Program) are designed to reduce development costs through a 'pay for practice' framework; however, these programs are in the testing phase. In the voluntary market, carbon offsets generated from an improved forest management project can sell for more than other projects because of the co-benefits included with keeping forests as forests (e.g., wildlife habitat, flood resilience). For projects that have occurred in New England, landowner revenue can range from $5-$25 per acre per year[50].

How long does it take to develop a forest carbon offset project?

From contract signing to selling of credits takes about 12 to 24 months with most current standards, but this depends on many factors like project type, location, forest heterogeneity, and time of year. New programs for family forests may have different timelines because project development methods differ.

What is the minimum land requirement?

The amount of forestland needed for a forest carbon offset project varies by the standard used but is generally more than 2000 acres. Refer to the table 'List of Forest Carbon Offset Project Developers'

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[50] For more details on ERT pricing see Forest Trends' Ecosystem Marketplace. Carbon Markets Hub and Keeton *et al*. Vermont Forest Carbon: A Market Opportunity for Forestland Owners. https://www.vlt.org/wp-content/uploads/2018/07/Vermont_Forest_Carbon.pdf

above. There are programs for forest parcels as small as 30 acres, but these programs are in development.

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