Forests and Carbon

A Guide for Buyers and Policymakers

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Executive Summary

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The 2020s are a critical decade for climate action. Natural climate solutions, and particularly forest-based strategies, hold tremendous potential for climate change mitigation.

02

Not all forest carbon strategies are created equal. The effectiveness of various strategies can be evaluated using **the new 'RISE' framework for impact: Real, Immediate, Scalable, and Efficient.** These criteria guide the efficient deployment of money to the right acres at the right time.

03

Although well-intentioned, existing forest carbon methodologies do not always achieve RISE impact. In extreme cases, landowners are paid to do what they might have done anyway. As a result, **resources spent pursuing these existing strategies fall short of accomplishing meaningful change.**

04

The Natural Capital Exchange (NCX) addresses these shortcomings and empowers all landowners to participate in forest carbon markets. It relies on advances in remote sensing technology to drive targeted, short-term timber harvest deferrals on an annual basis. This market-based, data-driven mechanism ensures that each year dollars flow to the right acres at the right time, creating Real, Immediate, Scalable, and Efficient climate impact.

05

By paying landowners to reduce annual harvests, NCX can increase the average forest carbon per acre and **remove up to 1.2 billion tons of carbon from the atmosphere this decade in just the US, and 4.3 billion tons globally.**

Introduction

Global enthusiasm for using **natural climate solutions** to fight climate change is on the rise, with research showing nature-based strategies could accomplish about a third of the emissions reductions needed to reach the Paris 2-degrees-Celsius target.[1] Forest-based solutions account for the lion's share of this total potential, leading to bold initiatives like the World Economic Forum's "One Trillion Trees" initiative.[2] Across the globe, policymakers, companies, and NGOs are rushing to find shovel-ready forest projects that can create **Real, Immediate, Scalable, and Efficient (RISE) climate impact**.

Forest carbon strategies have massive potential, but there are several known pitfalls that can dramatically reduce their effectiveness. Currently, the two main forest carbon strategies in the US are afforestation and the CARB (California Air Resources Board) Forest Offset Protocol—both of which are well-intentioned but suffer from structural issues which reduce their RISE impact. Afforestation, or planting trees on previously unforested land, takes decades to sequester meaningful amounts of carbon. The CARB protocol, under which over a billion dollars worth of forest carbon credits have been traded,[3] may be vulnerable to adverse selection and other issues stemming from its design.[4] Both of these strategies will be discussed in detail below.

Over the next few decades, hundreds of billions of dollars will be spent fighting climate change with the express goal of reducing future costs to society, and a significant portion will be directed to forest-based strategies. This paper lays out a framework and a solution for ensuring that money is spent wisely.

The answer? A highly targeted, short-term harvest deferral strategy, accessible to all landowners and underpinned by high-resolution forest data on every acre. This market-based solution ensures that each year dollars flow to the right acres at the right time to change landowner behavior and create RISE climate impact.

Selecting the most effective strategies requires understanding the economics of forest landowners, and further, how incentives can change landowner behavior. Historically, forest management has been largely driven by timber economics—harvesting and selling timber was the only way for forest owners to get paid. But we know that forests—alongside all their biodiversity, hydrological, cultural, and other benefits—also remove atmospheric carbon dioxide and sequester it in organic form. **An effective mechanism for paying landowners to grow more carbon in their forests will transform forest management and significantly increase carbon removals from the atmosphere**—up to an additional 4.3 billion tons globally this decade.[5]

[1] https://www.pnas.org/content/114/44/11645
[2] https://www.weforum.org/agenda/2020/01/one-trillion-trees-world-economic-forum-launches-plan-to-help-nature-and-the-climate/
[3] https://ww3.arb.ca.gov/cc/capandtrade/offsets/offsets.htm
[4] https://haas.berkeley.edu/wp-content/uploads/WP222.pdf
[5] https://www.researchgate.net/publication/337224237_Global_Woody_Biomass_Harvest_Volumes_and_Forest_Area_Use_Under_Different_SSP-RCP_Scenarios

Scope

Forestry is “the science, art, and business of creating, managing, and conserving forests and associated resources in a sustainable manner to meet desired goals, needs, and values”[6]; the complex interplay of ecology, economics, and culture of any given forest area dictates how forestry may best be practiced. This paper focuses on **forestry in the continental United States** because of its well-established forest industry, the high proportion of privately owned acres, and the availability of relevant data for modeling timber economics for every landowner. Unless specifically stated, all references to aggregate totals will refer to continental US totals.

Some sections of this paper contain detailed analysis of example properties. For these examples, this paper adopts **plantation forestry in the southern United States** as its simplified basis for analysis because its opportunities and constraints are relatively tractable. In this style of forestry, the trees on a given parcel are established all at the same time and, eventually, harvested all at the same time—and then the cycle begins anew.

While many of the specifics discussed here require adaptation to other contexts, the underlying principles provide guidance for forest contexts across the world.

[6] https://www.eforester.org/Main/Contact_Management/Broad_Field_of_Forestry.aspx

Carbon Pools

The core principle behind forest-based climate strategies is very simple: forests reduce the amount of carbon in the atmosphere by increasing the amount of carbon in trees. Despite a proliferation of confusing terminology around “offsets” and “insets,” “emission reduction,” and “removals,” the key metrics of success should remain the same: over time, how much carbon is in the atmosphere and how much carbon is in forests? For the avoidance of confusion, all discussion of “carbon” within this paper refers to metric tons of CO_2 equivalent ($MTCO_2e$).[7]

There is no way to make carbon “disappear” from our planet. Carbon simply moves from one pool, such as underground fossil fuel deposits, to another pool, such as the atmosphere. Therefore, the goal of forest-based climate action is to decrease the amount of carbon in the atmosphere by increasing the amount of carbon in forest biomass.

In other words, the primary outcome deserving focus is the total landscape forest carbon. Total landscape forest carbon is a function of both the number of forested acres and the average carbon per acre of forest:

`Total Landscape Forest Carbon = Forested Acres * Carbon Per Acre`

Note that while at times it may be useful to consider the carbon content of one particular property—which we will call individual property forest carbon—this should not be conflated with the all-important landscape measure. This delineation of the desired outcome sets the stage for evaluating the effectiveness of individual forest carbon strategies. To give some intuition about the current state of forests within the continental US[8]:

$51.4\text{Gt} = 684\text{M acres} * 75.2\ MTCO_2e \text{ per acre}$

Note that this paper treats the harvesting of timber as a transfer of carbon from the forest to the atmosphere, even if some of the biomass is turned into “durable wood products” like dimensional lumber for buildings. Why? A full life cycle analysis reveals that more carbon is emitted in the processing of these materials than is stored in the materials themselves. When one accounts for the emissions from harvesting, transportation, milling, and transport to a job site, building with wood is not carbon negative.[9] [10] While building with wood does have a much smaller carbon footprint than building with metal or concrete, these downstream substitution effects do not constitute part of our rubric for assessing forest carbon strategy impact. Actions taken in the forest—and their impact on total landscape forest carbon—are where we draw the boundaries of analysis.

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[7] https://www.yaleclimateconnections.org/2009/01/common-climate-misconceptions-co-equivalence/

[8] https://apps.fs.usda.gov/Evalidator/evalidator.jsp (Forest carbon pool 1: live aboveground)

[9] https://www.pnas.org/content/115/14/3663

[10] https://www.dogwoodalliance.org/wp-content/uploads/2019/09/Climate-Impacts-of-Industrial-Forest-Practices-in-NC-web.pdf

The ‘RISE’ Framework

Forest management resembles the ancient board game of Go. The set of possible moves is relatively small and those moves are relatively simple, but the arrangement of those moves in space and time creates a very complex set of outcomes. And unlike a Go board, which doesn’t change if you walk away, forests continue to grow and change constantly.

Readers versed in forestry will know that, across the globe, the set of optimal practices (or even the set of possible practices) varies widely. Decisions about regeneration and harvesting must be adapted to the local ecological and economic context.

As noted above, we have adopted United States plantation forestry as our simplified basis for analysis. In a stylized model of plantation management, a forest landowner can make two key “moves” to increase their individual property forest carbon:

01

Increase the area planted with trees.

Increasing the planted area will increase the number of forested acres, clearly, but it will also reduce the average carbon per acre: since the trees are small, a newly planted acre contains a tiny fraction of the carbon content of the average acre. The net effect is a small increase in individual property forest carbon.

02

Increase average forest carbon per acre by deferring timber harvest.

The longer trees are allowed to grow, or equivalently, the less harvesting activity is undertaken, the more carbon will be stored in each acre of forest. The net effect is an increase in individual property forest carbon.

The "moves" seem simple. So why is it so complicated to design strategies to reliably increase total landscape forest carbon?

As this paper will proceed to explore, **it is surprisingly complicated to draw a clear line between the actions taken on a single acre and the effect on the overall landscape.** There are millions of individual forest owners with a complex set of economic, ecological, and personal motivations. The actions taken by one owner on a single acre can change the ecological and economic dynamics on nearby acres owned by others. And of course, each individual acre of forest is unique and changes naturally over time. Accounting for future uncertainty—economic, ecological, and personal—is especially challenging when thinking about the decades- or centuries-long lifespans of trees.

Faced with a bewildering amount of complexity, how can we evaluate strategies that may increase the total landscape forest carbon on the planet? The RISE framework suggests four key questions that must be asked of any would-be forest carbon strategy:

R	**Real** | Does the strategy induce a real change in landowner behavior and result in more total landscape forest carbon?
I	**Immediate** | Does the strategy create near-term impact or is it in the distant future?
S	**Scalable** | How many billion tons of carbon can this strategy remove from the atmosphere this decade?
E	**Efficient** | What is the price per ton of carbon shifted from the atmosphere to the forest?

Two notes here. First, the RISE mnemonic also lists the criteria in rough order of importance. If a strategy's impact isn't Real, there is no point in evaluating its Efficiency!

Secondly, note also that instead of featuring in the RISE mnemonic directly, the crucial concepts of **permanence, additionality, and leakage** play central roles in our discussion of the Real and Immediate criteria. In other words, this framework aligns with the classical view of these concepts' importance.

In the following sections, we'll elaborate on the RISE framework and assess how various forest carbon strategies perform against its criteria. But first, a word on the basic types of strategies that will be discussed.

Two Main Types of Forest Carbon Strategy

Each of the forest management "moves" described above corresponds to a generic type of forest carbon strategy.

Increasing the area planted with trees is the basic idea of afforestation, reforestation, and reduced deforestation strategies. This paper adopts afforestation strategies as the "representative" of this type as we move through the RISE framework.

Afforestation / Reforestation

Establishing forest cover on land that was not previously forested

Reduced Deforestation

Preventing forested area from being cleared of trees and converted to another land use

On the other hand, **increasing average forest carbon per acre is the basic idea of improved forest management (IFM) strategies.**[11] This paper makes the distinction between coarse long-term IFM strategies, such as the CARB protocol, and targeted short-term IFM strategies.

Coarse Long-Term IFM

Paying landowners with existing forest carbon levels above regional averages to retain or increase those levels for 100 years

Targeted Short-Term IFM

Paying landowners to increase forest carbon per acre by deferring harvest activity (forecast algorithmically for each individual property) for 1 year

Having established the connection between the two available "moves" and the two basic "types" of forest carbon strategy, we can proceed to assess them using the RISE framework.

[11] IFM strategies are also sometimes referred to as "extended rotation age" strategies.

R: Real

What Do We Mean by Real?

Even in the absence of a concerted forest-based climate policy, the total landscape forest carbon in the United States has been increasing by about 446 million tons per year.[12] In fact, US forest growth has exceeded total harvests and mortality since at least 1976.[13]

A forest carbon strategy can be deemed Real if it increases total landscape forest carbon relative to what would have happened in the absence of the strategy. This is the first and most fundamental test of a potential strategy. We must determine that it demonstrably changed an individual landowner's behavior on that particular property, and also that the change was not canceled out by resultant changes on other properties across the landscape.

The Property Level: "Additionality"

Simply paying landowners to maintain their "business as usual" (BAU) does not create a 'Real' climate impact. The goal of an effective forest carbon strategy is to create "additional" forest carbon on the landscape above and beyond BAU. This is a concept known as "**additionality**."

The clarity of BAU varies widely depending on the type of forest carbon strategy. For example, in the context of an afforestation strategy, the presumptive BAU is very clear—BAU is that the land is not and will not be covered in forest without intervention.

BAU in IFM Strategies

BAU in the context of IFM strategies is more complicated and requires an understanding of forest economics. While the nuances of forest economics certainly vary across regions and types of forestry, the core principles can be understood by considering a plantation context.

Similar to crops like corn, trees in a plantation setting are planted, grown, and harvested. Unlike corn, however, the growing period (or the "**rotation age**") for trees is measured in years rather than months.

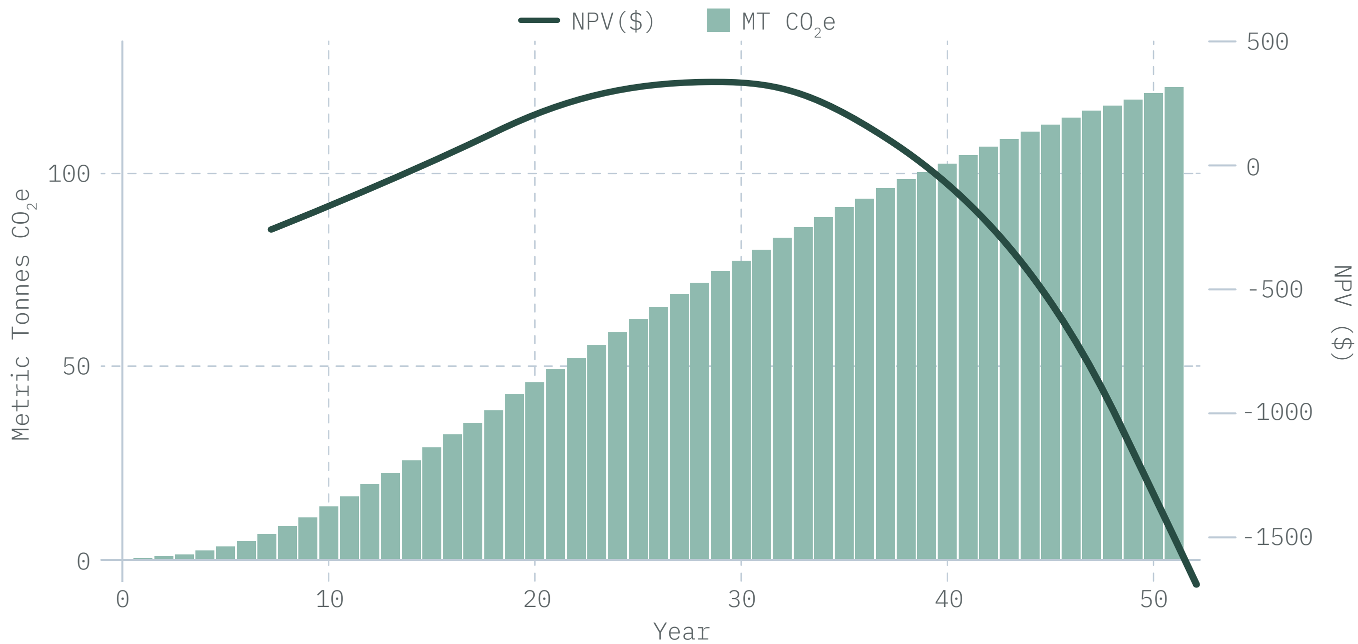
For any acre of forest, the **economically optimal rotation age** can be determined by considering the costs of planting, tree growth rates, prices paid for various timber products, harvesting costs, transportation costs to the mill, and the landowner's financial discount rate. Combining all of these factors together results in a graph that shows how a particular landowner's net present value (NPV) of

[12] https://www.everycrsreport.com/reports/R46313.html#_Toc39668492
[13] https://www.fia.fs.fed.us/library/brochures/docs/2012/ForestFacts_1952-2012_English.pdf

owning the forest changes as the rotation age increases. Landowners harvest when NPV[14] is maximized.

NPV approximates a bell-shaped curve. Generally, value increases as long as the value of harvestable timber increases faster than the discount rate, then reverses as the biological growth rate of the trees slows.

Figure 1: Net Present Value and Total Tons CO_2e



This graph has several implications for IFM strategies:

01 By definition, landowners should not need to be paid to manage their forests to an economically optimal rotation age—in the absence of any external payments, they will choose to do so anyway. As a corollary, any payments aimed at preventing landowners from managing to a shorter, economically sub-optimal rotation age would be redundant and not result in *additional* sequestration.

02 Conversely, landowners must be paid to extend the rotation age of their forest past the economically optimal point. In the absence of additional payments, the NPV of their forest declines. But for a large enough payment, the landowner might change their behavior and choose to defer harvest for some period of time.

03 Deferring harvest by a few years is “cheap” because the NPV curve is relatively flat near the economic optimum. However, the further a rotation is extended, the more expensive it becomes to compensate the landowner as NPV drops significantly.

[14] Actually the economically optimal harvest date is when the NPV of harvesting and re-planting in perpetuity is maximized. This concept is called the land expectation value (LEV). But the concept is the same.

Determining optimal rotation age from an NPV curve is trivial, but the construction of an NPV curve requires detailed data about every acre of a forest as well as other economic variables. However, this level of detail is absolutely necessary to develop a realistic, landowner-specific model of BAU harvest behavior.

Why Does This Matter?

Recall that BAU is critical to additionality, and additionality is required for Real impact at the property level.

Without a realistic BAU assessment, strategies run the risk of adverse selection[15], where payments are made to landowners to behave in ways that they might have behaved already. In extreme cases, landowners could get paid for forest carbon that would have been sequestered on their property whether they were paid or not.

Far from being an abstract concern, coarse BAU assessment has led to serious challenges for the real-world California Air Resources Board (CARB) Forest Offset Protocol.

The CARB protocol rules classify each acre of forest into one of several regional categories like "Central California Coast Redwood/Douglas-fir Mixed Conifer" or "Florida Coastal Plains Central Highlands Oak-Hickory." Each of these categories has a "common practice" baseline regional average level of carbon per acre associated with it, and forest properties with average carbon levels above this baseline can enroll in the program. Landowners receive upfront payment for existing carbon above the baseline and are required to manage their forest over time in a way that maintains or increases forest carbon levels even further above the baseline. This "common practice" approach was adopted in response to the difficulty of setting a baseline for each individual property,[16] which was more challenging at the time of CARB protocol design given data and computational limitations.

But historical limitations aside, the result is that if some landowners have already chosen, or would choose in the future, to manage above that baseline level or increase carbon levels for any reason (e.g. because they lack access to local timber markets), then they are eligible to receive payments that are not in fact necessary to maintain or increase the forest carbon on their properties. This adverse selection threatens to significantly reduce the additionality of the CARB protocol, and is a persistent problem for coarse long-term IFM strategies.

The Landscape Level: "Leakage"

Even if a strategy accomplishes real change on a particular property, that change may be counterbalanced and canceled out by changes in forests elsewhere. For example, if the level of harvest activity is restricted on one property, that activity may **simply shift to a different property nearby**, resulting in no net change in harvest activity across the landscape.

[15] https://www.sandiegouniontribune.com/news/environment/sd-me-carbon-credits-20180917-story.html
[16] https://www.pacificforest.org/wp-content/uploads/2019/08/tuttle-protocol-white-paper-20190823.pdf

This phenomenon is called “**leakage**” because the harvesting activity is “leaking” from the restricted project area onto surrounding forests. When it occurs, leakage reduces the impact of forest carbon strategies because it prevents well-intentioned individual landowner behavior changes—even changes that might increase individual property forest carbon—from increasing total landscape forest carbon. An effective forest carbon strategy will therefore be designed first to **minimize potential leakage**, and second, to **account for unavoidable leakage** and deduct that amount from the stated program impact. In IFM projects, we are concerned with two types of leakage: leakage within a landowner’s property, and leakage in the wider market.

Leakage Within an Owner’s Property

DEFINED

The first type of leakage happens within the land owned or managed by any participating landowner, and is often called “activity-shifting leakage.” This type of leakage would occur if a project participant shifted harvesting activity around within their property in response to participating in the project, such that a reduction in harvesting on the enrolled portion of their property was canceled out by an increase elsewhere on their land.

MINIMIZED

By definition, this type of leakage could only occur if a participant had a portion—but not all—of their landholdings enrolled in the project. Therefore, activity-shifting leakage can be effectively eliminated using an eligibility condition: to participate in the project, participants must enroll all of their owned or managed property.

ACCOUNTED FOR

Under this project design, since a participant’s entire property is measured and monitored, the risk of this type of leakage is effectively reduced to zero. This system represents a meaningful improvement over programs that allow landowners to pick and choose which of their acres to enroll.

Leakage Outside of Project Participant’s Property

DEFINED

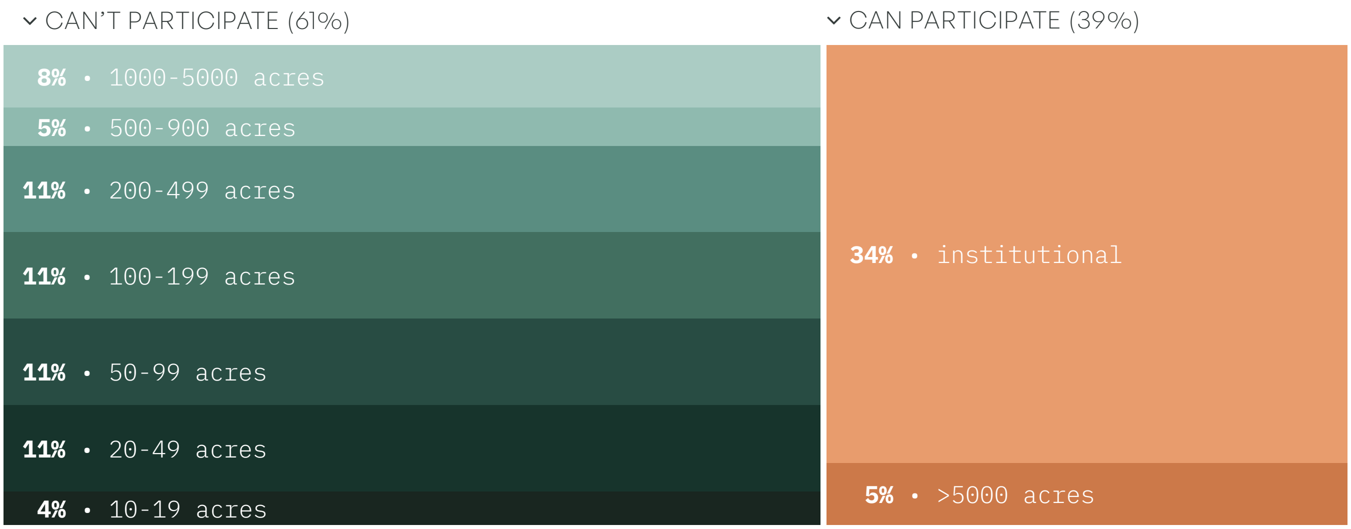
Leakage that occurs beyond the extent of the participants’ properties is called “market leakage.” Market leakage happens when the reduction of timber harvest in one place due to program activities shifts the equilibrium of supply and demand, increasing the pressure for timber harvests elsewhere. This increased harvest elsewhere may partially or fully cancel out the program’s intended impact.

MINIMIZED

One way to minimize market leakage is to make participation in carbon programs as accessible as possible; market leakage will almost certainly occur when not all forested acres can participate. When only one subset of landowners can receive payments to reduce timber harvests, harvests that would have taken place on their properties may readily “leak” onto adjacent properties that are excluded from the program.

The CARB protocol is particularly susceptible to this issue because of its relatively high transaction costs. These costs are not an intended feature of the protocol, but rather a side effect of its setup, verification, and monitoring requirements. Only landowners with approximately 5,000+ acres can profitably participate, meaning that most of the acres on the landscape (66% of privately owned forests[17]) are effectively excluded from participation. This may create significant potential for leakage, above and beyond the extent to which it is already acknowledged and addressed in the protocol through an ex post facto credit deduction.[18]

Figure 2: Proportion of Private Forest Acreage by Landowner Size and Ability to Participate in CARB



ACCOUNTED FOR

Though it may be minimized, market leakage cannot be fully eliminated. Therefore the effect must be accurately quantified and deducted from the declared impact of a carbon project.

Market leakage can be accurately quantified under an economic framework that considers the specific interplay between supply and demand in timber markets. This analysis rests on well-established forest economics parameterized with empirical data on the form of supply and demand. Using these factors, one can calculate the change in timber market equilibrium resulting from project activities, thereby deriving the "leaked" quantity of timber harvests. This quantity is then deducted from the project's total carbon removals. For more details, please refer to NCX's forthcoming technical memo on leakage assessment.

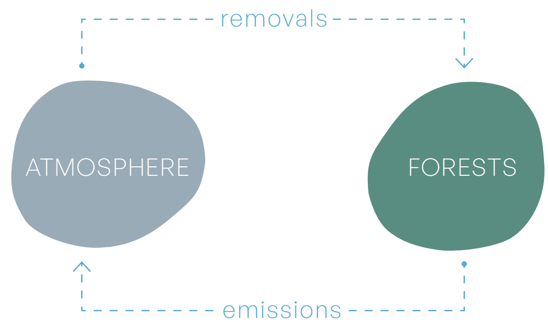
Once activity-shifting leakage and market leakage have both been fully accounted for, we can be assured that the carbon impact claimed by the project is indeed additional.

[17] https://apps.fs.usda.gov/nwos/NWOS_results.jsp (Area of private forests)
[18] https://gspp.berkeley.edu/assets/uploads/research/pdf/Policy_Brief-US_Forest_Projects-Leakage-Haya_2.pdf

"Emissions Reductions" vs. "Removals"

The goal of forest carbon strategies is to increase the amount of carbon in forests and thereby decrease the amount of carbon in the atmosphere. There are two flows that change the sizes of these two "pools":

- **Removals:** when trees grow, they remove carbon from the atmosphere and store it in woody biomass.
- **Emissions:** when trees decay or burn, they emit carbon directly into the atmosphere. Even when trees are harvested and milled, the carbon eventually returns to the atmosphere as the end product (e.g. paper or wood) rots. Deferring a timber harvest reduces emissions. (*See the 'Carbon Pools' section above for more discussion of this concept.*)



In theory, there is no difference in the climate impact between real removals and real emissions reductions. Both change the amount of carbon stored in the forest carbon "pool." A ton of carbon removed from the atmosphere for one year has identical climate impact to one ton of emissions deferred for one year.[19]

In practice, some carbon buyers have expressed a preference for carbon removals (for example, through afforestation projects) rather than deferred emissions (through IFM projects). In part, this reflects the pragmatic concern that existing coarse long-term IFM projects suffer from serious issues with additionality—there has been little "real" change in behavior, and therefore little change in the amount of atmospheric carbon.

A forest carbon strategy with a more targeted assessment of BAU gives forest carbon buyers confidence that their purchase is creating real change on the landscape.

Takeaways: Forest Carbon Strategies and the 'Real' Criterion

Requirements

Strong additionality through targeted BAU assessment. Low leakage through wide participation.

STRATEGY	ADHERENCE TO 'REAL' CRITERION	
Afforestation	STRONG	Clear additionality, leakage unlikely to occur.
Course Long-Term IFM	MODERATE	Some difficulty with additionality and leakage, due to coarse baselining and high enrollment costs.
Targeted Short-Term IFM	STRONG	Clear additionality and non-leakage, if harvest predictions are accurate and participation costs are low.

[19] For more on ton-year accounting, see the 'E: Efficiency' section

I: Immediate

What Do We Mean by Immediate?

A forest carbon strategy can be deemed Immediate if its climate impact accrues with very little delay after implementation.

The IPCC and others have made it clear that dramatic action needs to be taken by 2030 to avoid the worst consequences of climate change.[20] Sometimes lost in this dialogue, however, is the difference between "action" and "impact"; in many cases, the impact of a climate strategy lags far behind its implementation.

Immediacy in Forest Carbon Strategies

To assess forest carbon strategies with regard to immediacy, it will be helpful to recall the two basic "moves" a forest landowner can make in pursuit of increasing total landscape forest carbon, and the associated types of strategies:

01 Increase the number of forested acres (afforestation)
02 Increase average forest carbon per acre (IFM)

Increasing Forested Acres

For all its virtues, afforestation—planting trees in areas that were not previously forested—leads to **minimal present-day carbon sequestration**.[21] Though growth rates vary across species and potential planting sites, in all cases saplings take many years to begin accumulating meaningful amounts of carbon. Many of the costs, such as the financial costs of establishing trees and the opportunity cost of alternative land use, are paid upfront or front-loaded, but it takes decades to reap the climate benefits.[22]

This is not to conclude that afforestation does not belong in a portfolio of forest carbon strategies, just that one must be clear-eyed about its effective time horizons. The use of ton-year accounting, which is introduced in detail below in the 'E: Efficiency' section, will provide a quantitative framework for evaluating climate impact per dollar.

Increasing Average Forest Carbon Per Acre

All IFM strategies pay landowners to change their forest management practices over some period of time. The **term length** of these agreements has a direct bearing on the Immediacy of the climate

[20] https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf
[21] https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg3-chapter9-1.pdf
[22] https://fas.org/sgp/crs/misc/R40562.pdf

impact. Will the impact of the forest carbon strategy occur during this critical decade, or will it be diluted across decades in the distant future?

Coarse long-term IFM strategies have term lengths that stretch many decades into the future. For example, the CARB protocol has a 100-year term. This means that present-day resources are paying for a stream of benefits spread all across those 100 years. While at first glance it may seem that a decades-long contract is the best way, or perhaps even the only way, to achieve long-lived impact, this presumption is not correct. The 100-year approach unfortunately creates both **less flexibility** and the potential for **capital inefficiency**.

In contrast, targeted short-term IFM strategies create Immediate climate impact by deferring the imminent harvest of mature trees for one year—climate impact occurs in the same year payments are made. These mature trees not only contain a large amount of biomass, but they also remove more carbon from the atmosphere as they continue to grow for an additional year. This type of strategy offers greater capital efficiency and preserves flexibility while still offering “durable” or “permanent” climate impact. Capital efficiency is discussed further in the ‘E: Efficiency’ section; flexibility and permanence are addressed here.

Flexibility

Because we know that climate change is a long-term challenge, one might think long-term contracts would be a natural fit.

On the contrary, long-term contracts have the significant downside of ceding the option to change course or adapt in the future. Indeed, uncertainty about future technologies, economic conditions, and even our society’s shifting values should actually lead us to **prefer flexible solutions that can adapt over time**. Would you like to be bound today by the terms of a contract signed by your great-grandparents in 1920—a contract written with the scientific understanding and social context of the time?

Afforestation and coarse long-term IFM strategies are inherently inflexible. By construction, each of them commits to a specific course of action for decades, whether that’s incurring the high cost of planting or purchasing a 100-year contract.

The problem with this inflexibility is that it is potentially extremely inefficient. There is no way of knowing today whether these projects will prove to be cost-effective over the next decade, let alone their entire lifetimes. It seems likely, in fact, that cheaper alternative carbon sequestration technologies will eventually emerge.

In contrast, a targeted short-term IFM strategy preserves flexibility by reallocating payments each year to the cheapest carbon on the landscape. It is the most efficient and “optimal” solution.[23] At the conclusion of a one-year contract term, a property could re-enroll to receive payments if the economics were still favorable, or alternatively, payments could flow to a different property altogether and “shift” the carbon across space. And if non-forest-based carbon strategies, such as direct air

[23] https://econpapers.repec.org/article/oupajagec/v_3a85_3ay_3a2003_3ai_3a2_3ap_3a448-457.htm

capture, prove to be more efficient, then short-term harvest deferrals allow the sequestration burden to be nimbly shifted to another carbon pool entirely. Neither of these reallocations (across properties nor across carbon pools) are possible with other forest carbon strategies.

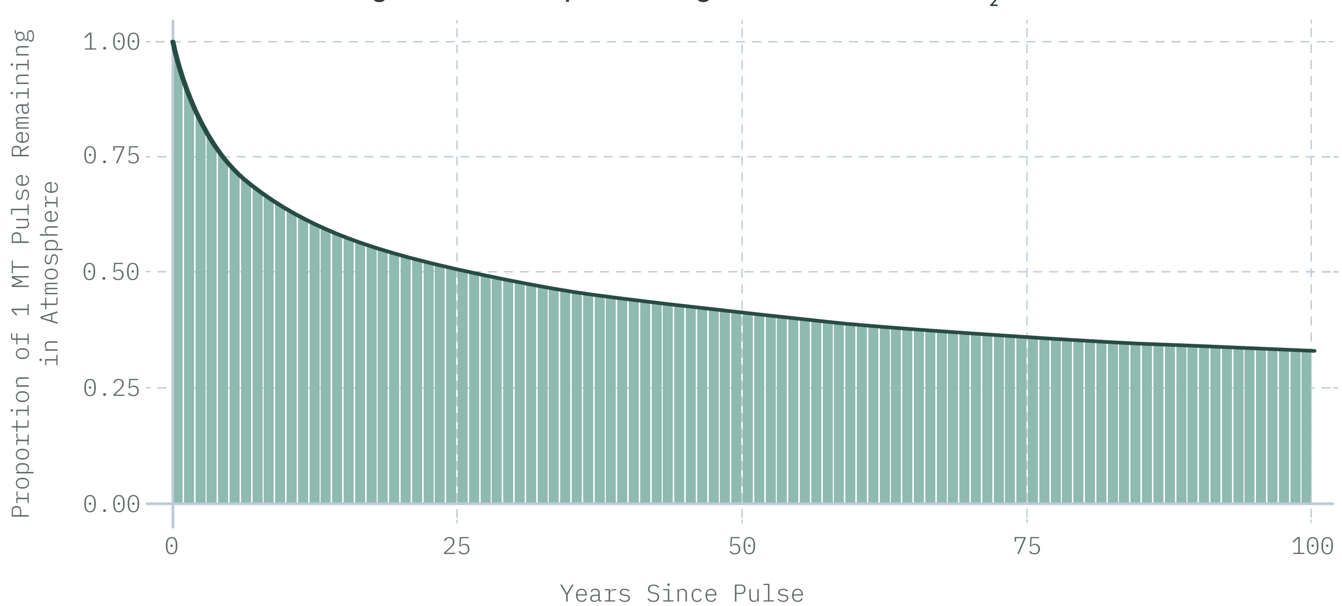
“Permanence”

CO_2e and Atmospheric Residence

Greenhouse gas emissions in nearly all contexts are denominated in units of **metric tons carbon dioxide-equivalent (MT CO_2e)**.[24] One MT CO_2e is defined as the **warming impact** of one ton of emitted CO_2 in the atmosphere, over a period of 100 years, and is used as a standard to compare the climate impacts of different greenhouse gases.

When 1 ton of CO_2 is emitted into the atmosphere, it gradually moves to other carbon sinks over subsequent years through naturally occurring biogeophysical processes. These processes slowly reduce the proportion of the emitted ton of CO_2 that resides in the atmosphere year over year. Some amount of CO_2 from the initial emissions pulse persists, however, over the decades, resulting in the decreasing curve of atmospheric carbon residence depicted below.[25] Because of the long time horizon for atmospheric carbon residence, the international standard for CO_2e limits its measurement to 100 years. Therefore, in the graph below, 1 ton CO_2e is represented by the area under the curve, truncated at 100 years.

Figure 3: Atmospheric Degradation of 1 Ton CO_2[26]



[24] For clarity, this paper uses “MT”, “ton”, and “tonne” interchangeably in reference to a metric tonne (1,000 kg).

[25] It is important to note that additional carbon removals sequester CO2 in excess of these natural processes. (https://acp.copernicus.org/articles/13/2793/2013/acp-13-2793-2013.html)

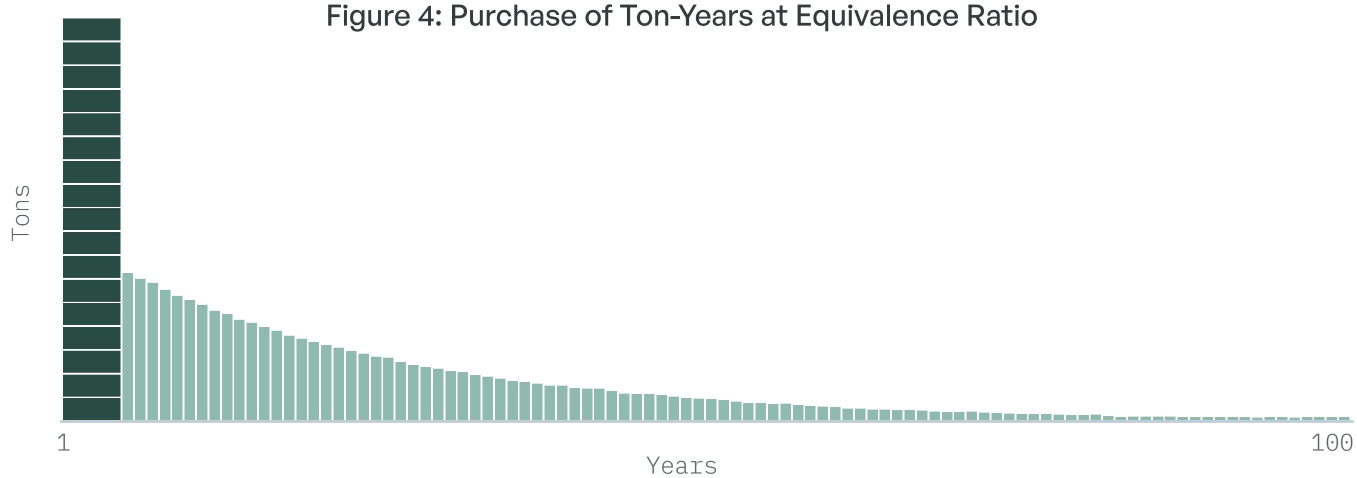
[26] Ibid

Ton-Year Accounting

To account for the impact of 1 ton CO_2e with greater temporal precision, we use a unit called a **ton-year**. One ton-year is defined as 1 ton of CO_2 residing in the atmosphere for one year. So, 1 ton CO_2e, or the area under the residence curve, can be expressed as the climate impact of the total number of tons of atmospheric carbon present over 100 years. In other words, based on the shape of this curve, 1 ton CO_2e is equal to a stream of about **53 ton-years, delivered over 100 years**.[27]

So what does this have to do with carbon removal? To completely cancel out the climate impact created by emitting 1 ton CO_2, one would need to remove and hold some magnitude of carbon, for some duration of time, to generate a climate impact equal to 1 ton CO_2e. The international community calls a unit of removal with impact equal to 1 ton CO_2e a "**permanent ton**."

Figure 4: Purchase of Ton-Years at Equivalence Ratio



Present-Day Climate Impact

To evaluate future streams of climate impact, economists "generally advocate that we discount benefits in the future relative to costs incurred today."[28] Abating the emission of 1 ton CO2e today implies a future benefit that we can convert to present-day value by applying a discount rate. As Nobel Prize-winning climate economist William Nordhaus writes, there exist "temporal trade-offs … between the costs of emissions reductions today and the societal value of reduced damages in the future. So a full appreciation of the economics of climate change cannot proceed without dealing with discounting."[29] Research on the subject demonstrates significant consensus around using a discount rate of 3.3% for carbon, which is consistent with both the social cost of carbon and the international standard for CO_2e.[30]

[27] https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter2-1.pdf

[28] The Climate Casino, William Nordhaus (2013).

[29] Ibid.

[30] For greater detail on the derivation of 3.3% as a discount rate consistent with the IPCC's standard for CO2e, please consult our forthcoming technical bulletin on permanence, discounting, and GWP, as well as Mallapragada and Mignone (2020) (https://esd.copernicus.org/articles/9/1013/2018/) and Sarofim and Giordano (2018) (https://link.springer.com/article/10.1007/s10584-019-02486-7).

Applying a 3.3% discount rate, we find that **1 ton of CO_2e, or 48 ton-years over 100 years, is equal to 30.8 ton-years today**. Mathematically, removing 30.8 ton-years from the atmosphere today achieves the same impact as 1 ton CO2e. So, removing and storing 30.8 tons CO_2 for one year, this year, has an equivalent climate impact to removing 1 ton CO_2e, or 1 "permanent ton."

Applying a 3.3% discount rate makes it possible to store greater magnitudes of carbon over shorter time periods, while retaining equivalence to tons of CO_2e. One significant advantage of the ton-year approach is that it makes it possible to implement a "payment on delivery" system for carbon removals. In the hypothetical discussed above, climate impact equal to 1 ton CO_2e is fully delivered at the end of one year, with no potential for future reversals (e.g. from wildfires). This means that there is no need for future liability, which is otherwise difficult to contract and confirm. Payment on delivery is one of the benefits that makes ton-years a critical advance in carbon accounting.

In summary, a targeted short-term IFM strategy not only **offers equivalence to "permanent tons" of impact**, but does so with **greater flexibility** in terms of storage and with greater **assurance against reversals**.

Takeaways: Forest Carbon Strategies and the 'Immediate' Criterion

Requirements

- Little delay between action and impact
- Climate impact during this critical decade
- Flexibility to adapt to changing circumstances
- Attainment of "permanent" impact

STRATEGY	ADHERENCE TO 'IMMEDIATE' CRITERION	
Afforestation	POOR	Newly established trees take years or decades to accumulate significant carbon.
Course Long-Term IFM	POOR	Impact is spread over years or decades. 100 year "lock in" limits adaptability to changing circumstances.
Targeted Short-Term IFM	STRONG	Impact occurs in the same year as implementation. Short term frame allows flexible reallocation of spending over space and time.

S: Scalable

What Do We Mean by Scalable?

A forest carbon strategy can be deemed Scalable if it can be feasibly expanded to a magnitude where it has a material impact on global climate change mitigation.

Even if a strategy can create a Real and Immediate impact, its usefulness will be limited if it cannot grow to a significant scale. Given that US carbon emissions exceed 6.5 billion tons a year,[31] strategies that can result in gigaton-magnitude carbon sequestration over the next decade deserve the most attention.

Scalability in Forest Carbon Strategies

A cursory look at summary statistics suggests American forests are large enough to have gigaton-scale potential:

Forested Acres, Continental US: 684 million[32]
Total Landscape Forest Carbon: 51.4 billion tons CO_2e[33]
Annual Forest Growth (Gross): 1.3 billion tons CO_2e[34]
Annual Forest Harvests (Drain): 508 million tons CO_2e[35]

But what about specific forest carbon strategies? Once again, we can turn to the two stylized "moves" to understand the potential scalability of various strategies:

01 Increase the number of forested acres (afforestation)
02 Increase average forest carbon per acre (IFM)

Increasing Forested Acres

Ecologically speaking, there are approximately 490 million acres of unforested land in the US that are suitable for planting trees.[36] Only a small fraction of this area is actually available for planting, however,

[31] https://cfpub.epa.gov/ghgdata/inventoryexplorer/
[32] https://apps.fs.usda.gov/Evalidator/evalidator.jsp
[33] https://apps.fs.usda.gov/Evalidator/evalidator.jsp (Forest Carbon Pool 1, live above ground)
[34] https://apps.fs.usda.gov/Evalidator/evalidator.jsp (Average annual gross growth of aboveground biomass of trees)
[35] https://apps.fs.usda.gov/Evalidator/evalidator.jsp (Average annual harvest removals of aboveground biomass of trees)
[36] https://www.fs.fed.us/pnw/pubs/pnw_gtr888.pdf

with the vast majority being used for other purposes, such as agriculture.[37] In most cases, the cost of purchasing the land or otherwise securing the right to plant trees would be prohibitive.[38] The economics of this strategy are assessed more in the 'E: Efficiency' section below.

Even if we set aside this potentially high cost, newly planted trees store very little carbon and take decades to grow to maturity. If 100 million non-forested acres were somehow planted today, perhaps only 0.5Gt would be removed from the atmosphere over the next decade.[39]

Increasing Average Forest Carbon Per Acre

If all US timber harvests were completely deferred for the next decade, two forest carbon impacts would be realized. First, the deferred harvests themselves:

`~500 million tons per year for 10 years = 5 billion tons of carbon`

And second, growth. Since those forests were left to grow, they could remove an additional 1 billion tons of carbon.

Combined, that would result in a total of **6 billion tons (gigatons) of additional carbon** in the forest and out of the atmosphere.

Of course, forest products are used in all manner of essential consumer and industrial products, so there is no case in which harvests are halted completely. Thus **6 gigatons represents a conceptual upper bound** on sequestration under such a strategy, and the realized impact will be considerably less.

Existing coarse long-term forest carbon strategies are not equipped to realize the conceptually large potential impact. Historically, most forest carbon strategies have been structured around boutique individual projects. The high setup costs for these projects limits their scalability. For example, a typical CARB protocol project may take two years and $200K to set up. The 100-year term on these projects is also unacceptable for many landowners,[40] preventing even more from participating.

As covered in the 'R: Real' section above, ultimately these structural issues **effectively exclude small landowners**[41] (defined here as anyone owning fewer than 5,000 acres) from participating in today's carbon markets. This is hugely problematic in the US, where small landowners in aggregate own over 200 million acres of forest.[42]

Small landowners must be included in a forest carbon strategy to achieve truly Scalable impact. When they are, the strategy will stand its best chance of achieving gigaton-level impact this decade. This will only be possible if setup costs are minimized and contract terms are much shorter than 100 years.

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[37] https://fas.org/sgp/crs/misc/R40562.pdf
[38] Ibid
[39] Ibid
[40] https://link.springer.com/article/10.1186/s40663-019-0 175-1
[41] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0201967
[42] https://www.fs.fed.us/nrs/pubs/jrnl/2016/nrs_2016_butler_001.pdf

Takeaways: Forest Carbon Strategies and the ‘Scalable’ Criterion

Requirements

- Gigaton-level impact in the US
  - Ecological capacity
  - Low barriers to participation for all landowners

STRATEGY	ADHERENCE TO ‘SCALABLE’ CRITERION	
Afforestation	MODERATE	Implementation scale limited by available land; impact scale limited by slow tree growth.
Course Long-Term IFM	MODERATE	High transaction costs and long commitment periods prevent many landowners (especially small ones) from participating.
Targeted Short-Term IFM	STRONG	Open to all landowners as long as transaction costs are kept low.

E: Efficient

What Do We Mean by Efficient?

A forest carbon strategy can be deemed Efficient if it maximizes present climate benefit per dollar of present cost.

To compare forest carbon strategies against each other in this section, we will use the establishment of plantation pine on marginal agricultural land in Mississippi as a stylized example. We'll also introduce discount rates to the discussion. This temporal analysis will lead naturally to (and require) the concept of a **"ton-year,"** which is defined as one metric ton (MT) of carbon dioxide-equivalent sequestered for a time period of 1 year. Critically, since a ton-year today is more valuable than a ton-year tomorrow, we will use the US EPA's "social cost of carbon" discount rate of 5% to bring all carbon sequestration from each strategy into present-day terms.[43] In doing so, we implicitly incorporate the prior discussion of timing under the 'I: Immediate' section. Efficiency considers both timing and cost.

Efficiency Across Forest Carbon Strategies

One final time, let's recall the two stylized "moves" to assess the potential efficiency of various strategies:

01 Increase the number of forested acres (afforestation)
02 Increase average forest carbon per acre (IFM)

Increasing Forested Acres

Assessing afforestation requires several assumptions about the example Mississippi acre. Land like this could be rented today for about $34 per acre per year.[44] Biologically, it is fairly generous to assume that a "typical" plantation pine rotation could be grown on this land. Establishing such an acre with pine costs about $275, and then ongoing management costs about $5 per year.[45] Assuming a standard yield table and timber prices,[46] and a landowner discount rate of 5%,[47] the optimal rotation age is 27 years. Therefore the present value of all costs is about $850.[48]

[43] https://www.wri.org/publication/time-value-carbon-and-carbon-storage
[44] The USDA Conservation Reserve Program (CRP) rents this type of land from landowners for various conservation purposes. The 2020 annual rental rate in Greene County, MS, is $34 per acre per year. For more information see https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/ and https://www.ngfa.org/newsletter/usda-releases-crp-rental-rates-grants-higher-rates-to-121-counties/
[45] http://www.afoa.org/PDF/n180312a.pdf
[46] TimberMart-South Q1 2020
[47] https://home.kpmg/content/dam/kpmg/us/pdf/2017/10/2017-timberland-investor-sentiment-survey-2017-brochure-final.pdf
[48] This entire analysis is conducted on an inflation-adjusted basis.

The below table displays the amount of carbon sequestered on this acre each year, the discounted (i.e. present-day) ton-years from that sequestration, and the cumulative present-day ton-years.

Table 1: Present Day Ton-Years Generated by Afforestation

Year	Carbon Ton-Years Generated in This Year from Existing Trees	Carbon Ton-Years Generated in This Year from New Growth	Total Carbon Ton-Years Generated in This Year	Total, Discounted to Today at 3.3%	Cumulative Discounted (Present Day) Ton-Years
1	0.0	0.1	0.1	0.1	0.1
2	0.1	0.4	0.5	0.4	0.5
3	0.5	0.7	1.1	1.1	1.6
⋮					
26	62.3	3.2	65.5	29.1	398.3
27	65.5	3.1	68.6	29.5	427.8

*Note: Columns may not sum due to rounding.

Thus for this stylized acre, the results are:

- Present cost of afforestation = about $850
- Present benefit in ton-years = about 430
- Cost/ton-year: **about $2**

The exact results for a particular acre will of course depend on the establishment cost assumptions, the biological growth rate of the trees, and the discount rates used, but in all cases the long time horizon for carbon accumulation will lead to a relatively high present cost per present ton-year.

Increasing Average Forest Carbon Per Acre

For a CARB protocol project, a present cost-benefit analysis can be completed similar to the one for afforestation above.

The present cost of 1 ton of carbon through a 100-year CARB contract is approximately $15.[49]

To determine the present benefit denominated in ton-years, an assumption must be made about the timing of the avoided future reduction in carbon stored on the property. Let's assume it would have taken

[49] Recall from above that under the CARB methodology landowners are contracted and (potentially) paid for two things: first, they are paid upfront for ensuring against any reductions in average forest carbon on the property; and second, they are paid over time for any increases in average forest carbon on the property. Since the upfront payments likely represent the majority of project value in most cases, the "avoided future reduction" mechanism of the credit will be the subject of analysis here.

place in 20 years.[50] Therefore, buying 1 credit today is buying a stream of carbon ton-years, 1 per year for 80 years, beginning in 20 years. Discounting this stream of ton-years to present terms equates to about 8.5 ton-years.

Thus for this stylized credit purchase, the results are:

- Present cost of the credit = about $15
- Present benefit in ton-years = about 8.5
- Cost/ton-year: **about $1.77**

This coarse long-term IFM strategy is therefore similarly efficient as afforestation.

But what about a targeted short-term IFM strategy? How much does a ton-year cost in this case?

The Real section above explained how optimal rotation age in a plantation system is determined by maximizing landowner NPV, which incorporated a landowner discount rate. By the same rationale, a landowner should be willing to defer a timber harvest if they are compensated for the time value of waiting 1 year, taking into account any extra timber growth and any extra costs they incur.

Furthermore, recall that the NPV curve is relatively flat near the optimal rotation age. Extending a timber rotation by a year or two only results in a minor decrease in NPV for the landowner.

This means that the compensation required to change landowner behavior is relatively low at this point. In fact, extending the rotation age by one year creates the lowest cost additional carbon on the landscape.

The table below shows the effect of deferring a timber harvest for one year on the example pine plantation in Mississippi.

Table 2: Carbon Ton-Years and Timber Economics for 1 Year Harvest Deferral

Age	Carbon Ton-Years Generated in This Year from Existing Trees	Carbon Ton-Years Generated in This Year from New Growth	Total Carbon Ton-Years Generated in This Year	Timber Value	Management Cost	NPV of Harvest
27 (BAU)	–	–	–	$1,635	–	$1,635
28 (1 Year Deferral)	68.6	3.0	71.6	$1,707	$5	$1,621

We see that in this example, the landowner would need to be paid $1,635 – $1,621 = about $14 per acre to defer the timber harvest.

[50] This avoided future reduction could take place at any point during the 100-year contract term, or not at all. Assuming it would have taken place in 20 years is, if anything, fairly generous.

Bringing all costs and benefits to the present, the results on a per-acre basis are:

Present cost to defer harvest = about $14
Present benefit in ton-years = about 72
Cost/ton-year: **about $0.20**

On a present cost-benefit basis, a targeted short-term IFM strategy has the potential to be an **order of magnitude more efficient** than the alternatives.

Takeaways: Forest Carbon Strategies and the 'Efficient' Criterion

Requirements

- Low present cost to present benefit
- Finds lowest cost carbon on landscape

STRATEGY	ADHERENCE TO 'SCALABLE' CRITERION	
Afforestation	POOR	High up-front costs plus heavily discounted future benefits due to time lag.
Course Long-Term IFM	POOR	100-year term allocates present-day dollars to heavily discounted future impacts.
Targeted Short-Term IFM	STRONG	100-year term allocates present-day dollars to heavily discounted future impacts.

NCX: The Nature of Capital Exchange

The case is clear: a coherent forest carbon strategy must be Real, Immediate, Scalable, and Efficient. The sections above have explained what these principles mean and used them to assess various forest carbon strategies:

STRATEGY	REAL	IMMEDIATE	SCALABLE	EFFICIENT
Afforestation	STRONG	POOR	MODERATE	POOR
Course Long-Term IFM	MODERATE	POOR	MODERATE	POOR
Targeted Short-Term IFM	STRONG	STRONG	STRONG	STRONG

The RISE framework suggests the need for a targeted short-term IFM strategy.

NCX is that strategy.

What is NCX?

With the creation of its carbon marketplace, NCX has reimagined forest carbon markets. The Natural Capital Exchange turns forest carbon supply from landowners of all sizes into quality carbon credits.

NCX is Real

Requirements

- Strong additionality through targeted BAU assessment.
- Low leakage through wide participation.

NCX capitalizes on **recent technological advances** that have made it possible to estimate the sizes and species of trees on every acre of forest, every year.[51] This not only enables an assessment of the amount of carbon on every forested acre, but also makes it possible to construct an NPV curve and develop a model of landowner timber harvest behavior. This allows for a much better BAU assessment. The methods used by NCX for these harvest behavior predictions are empirically estimated following peer-reviewed methods.[52] Ultimately, the clearest validation of BAU prediction accuracy will come from landowners' willingness to participate in the market.

[51] www.ncx.com/basemap

[51] Atmadja, Stibniati S., and Erin O. Sills. "Forest management and landowners' discount rates in the Southern United States." *Post-Faustmann forest resource economics*. Springer, Dordrecht, 2013. 91-123.

At the end of the one year contract term, the landowner receives credit for the amount of harvest reduction relative to their individualized BAU scenario.

Wide participation, and thus reduced potential for leakage, is ensured by opening the program to landowners of any size.

NCX is Immediate

Requirements

- Little delay between action and impact
- Climate impact during this critical decade
- Flexibility to adapt to changing circumstances
- Attainment of “permanent” impact

When a buyer purchases an NCX forest carbon credit, they are buying immediate change on the landscape. Landowners are paid, and credits are issued, only upon verification of harvest deferral at the end of the one year term. Participants in NCX demonstrably contribute to the urgent need for action by 2030.

Short contract terms allow all market participants to flexibly adjust to changing conditions over time.

NCX is Scalable

Requirements

- Gigaton-level impact in the US
  - Ecological capacity
  - Low barriers to participation for all landowners

NCX radically **democratizes access to forest carbon markets** through low transaction costs, no minimum acreage size, and short contract terms. By massively expanding the ability of all landowners—both large and small—to participate in carbon markets, NCX can mobilize the 684 million acres of US forests to achieve gigaton-level impact.

That’s why NCX’s use of satellite imagery, cloud computing, and algorithmic estimation is so crucial. It dramatically reduces implementation costs.

NCX is Efficient

Requirements

- Low present cost to present benefit
- Finds lowest cost carbon on landscape

NCX achieves efficiency in two ways that other carbon strategies cannot claim.

First, by paying to defer harvest activity when trees are still growing vigorously, NCX ensures the cost of a carbon "ton-year" is as low as possible. This efficiency is part and parcel of the deferred harvest methodology itself.

Second, the price of an NCX carbon credit will be set by an annual auction, which matches supply and demand at the lowest possible price. As economic conditions change and the ecological landscape evolves over time, payments will annually readjust and flow to the new lowest-cost acres.

Why NCX? Why Now?

This is a critical decade for the climate. Forests can play an important role in combating climate change, but existing forest-based strategies fail to achieve RISE climate impact. This paper has introduced the RISE framework to help carbon buyers and policymakers evaluate forest-based climate strategies in the context of the existing timber industry and current forest management practices.

NCX's Natural Capital Exchange, or NCX, is the strategy that performs best against the RISE framework. It relies on advances in remote sensing technology to drive targeted, short-term timber harvest deferrals on an annual basis. This market-based, data-driven mechanism ensures that each year dollars flow to the right acres at the right time to create a Real, Immediate, Scalable, and Efficient climate impact.

For more information, visit NCX.com.