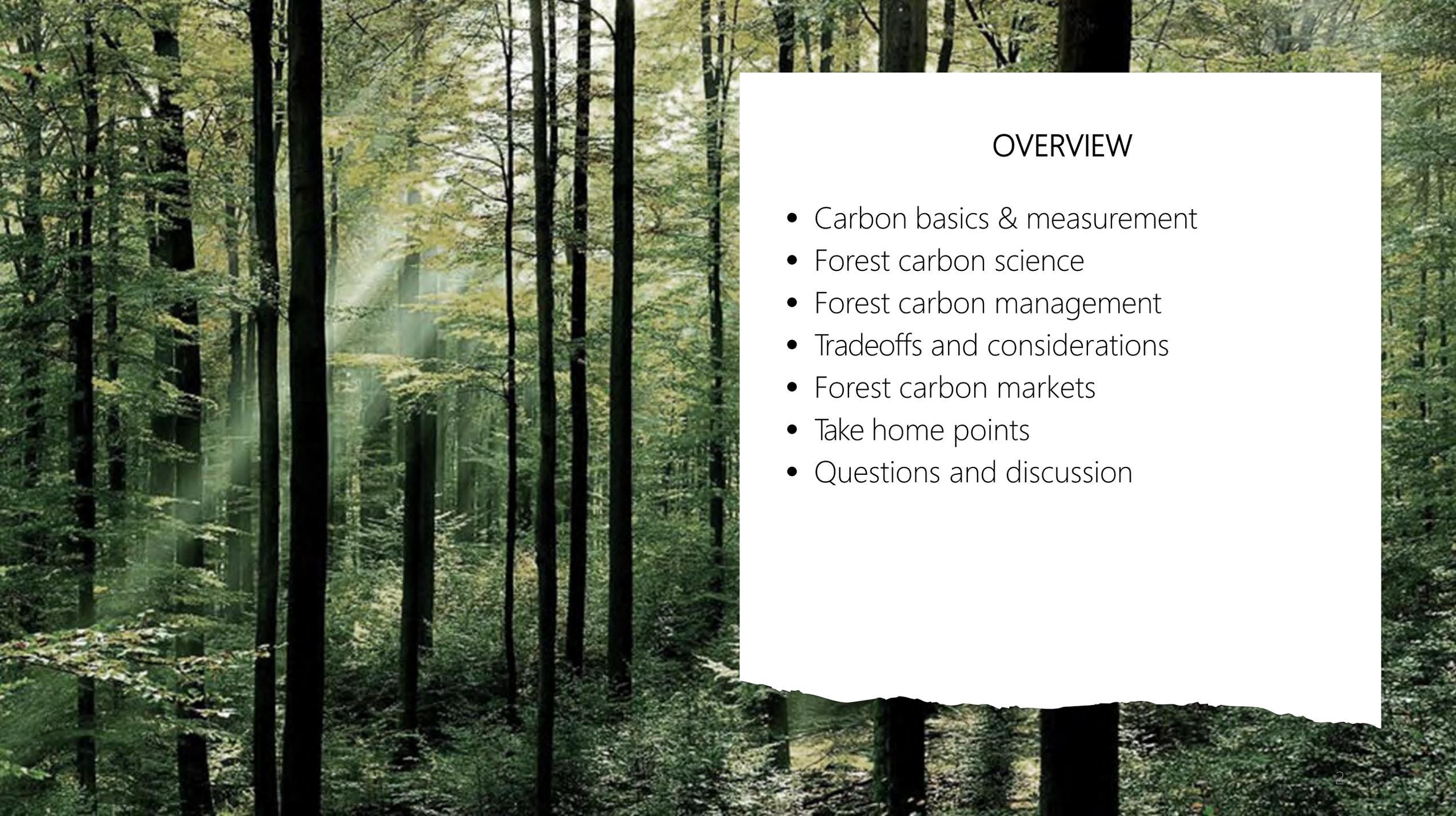


# Introduction to Forest Carbon: Science, Management, and Markets

Christopher Riely, University of Rhode Island

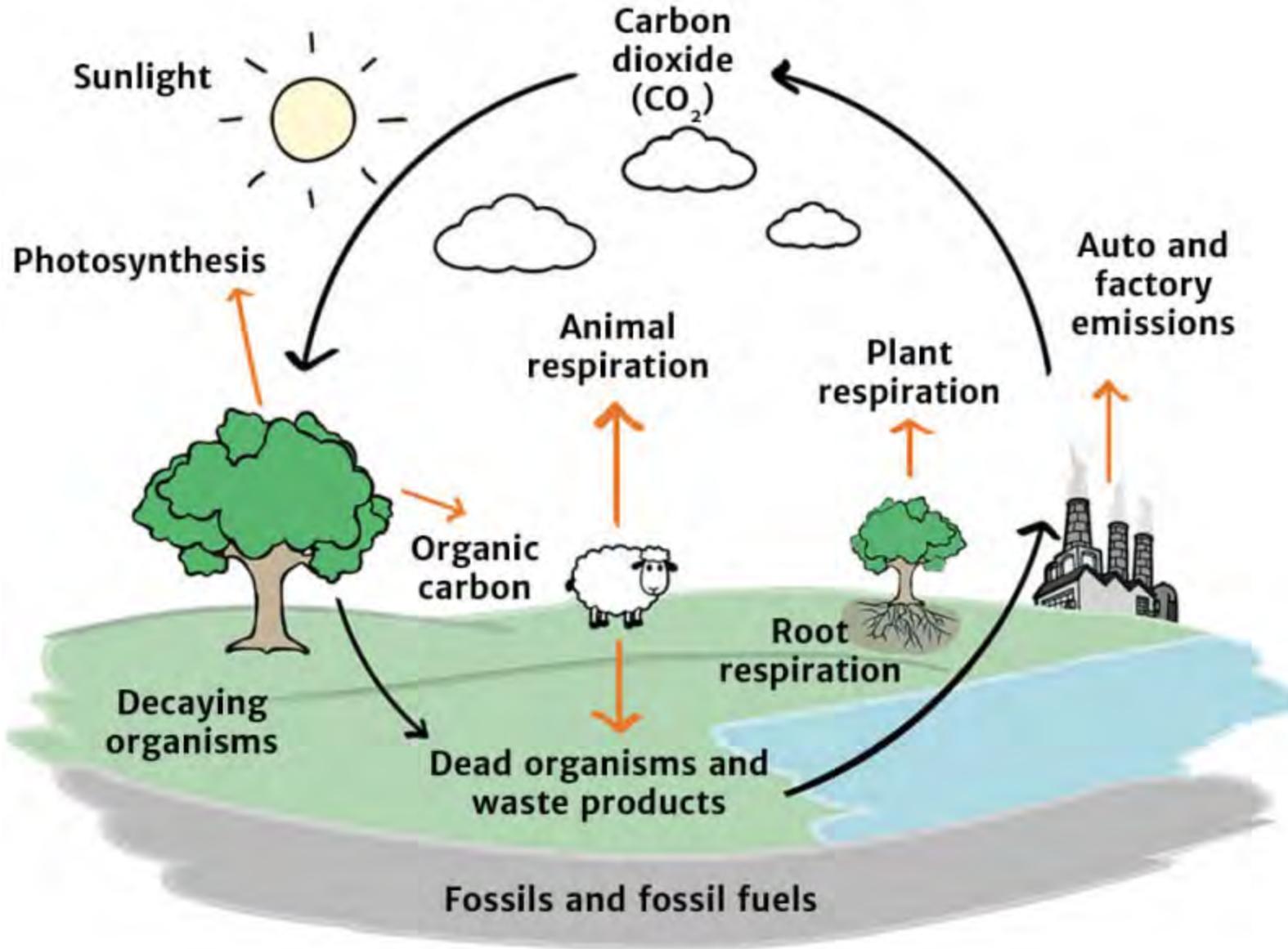
*Content and many slides adapted from presentations by:*  
Dr. Ali Kosiba, Vermont Dept. Forests, Parks and Recreation  
Securing Northeast Forest Carbon Program



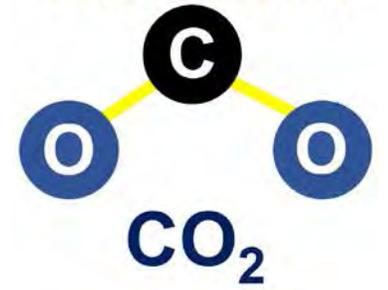
## OVERVIEW

- Carbon basics & measurement
- Forest carbon science
- Forest carbon management
- Tradeoffs and considerations
- Forest carbon markets
- Take home points
- Questions and discussion

# Carbon Cycle



Carbon Dioxide

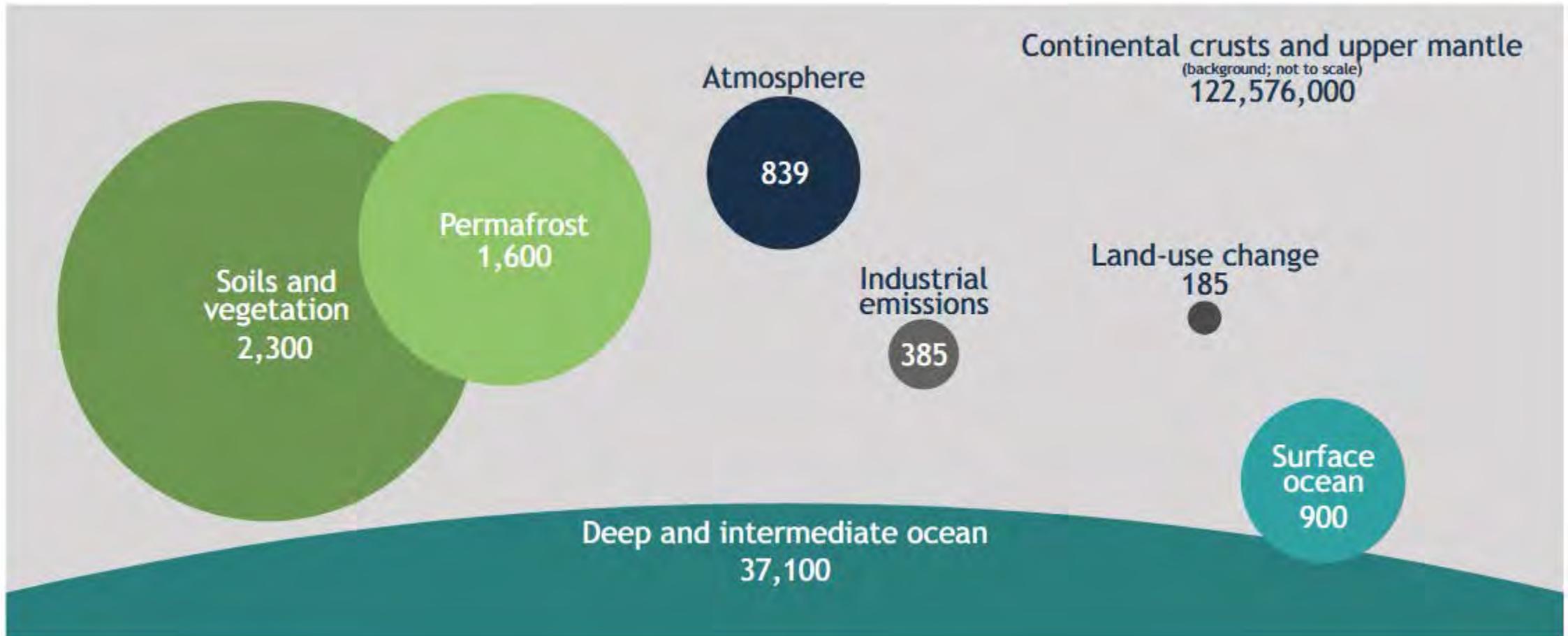


Nearly pure carbon



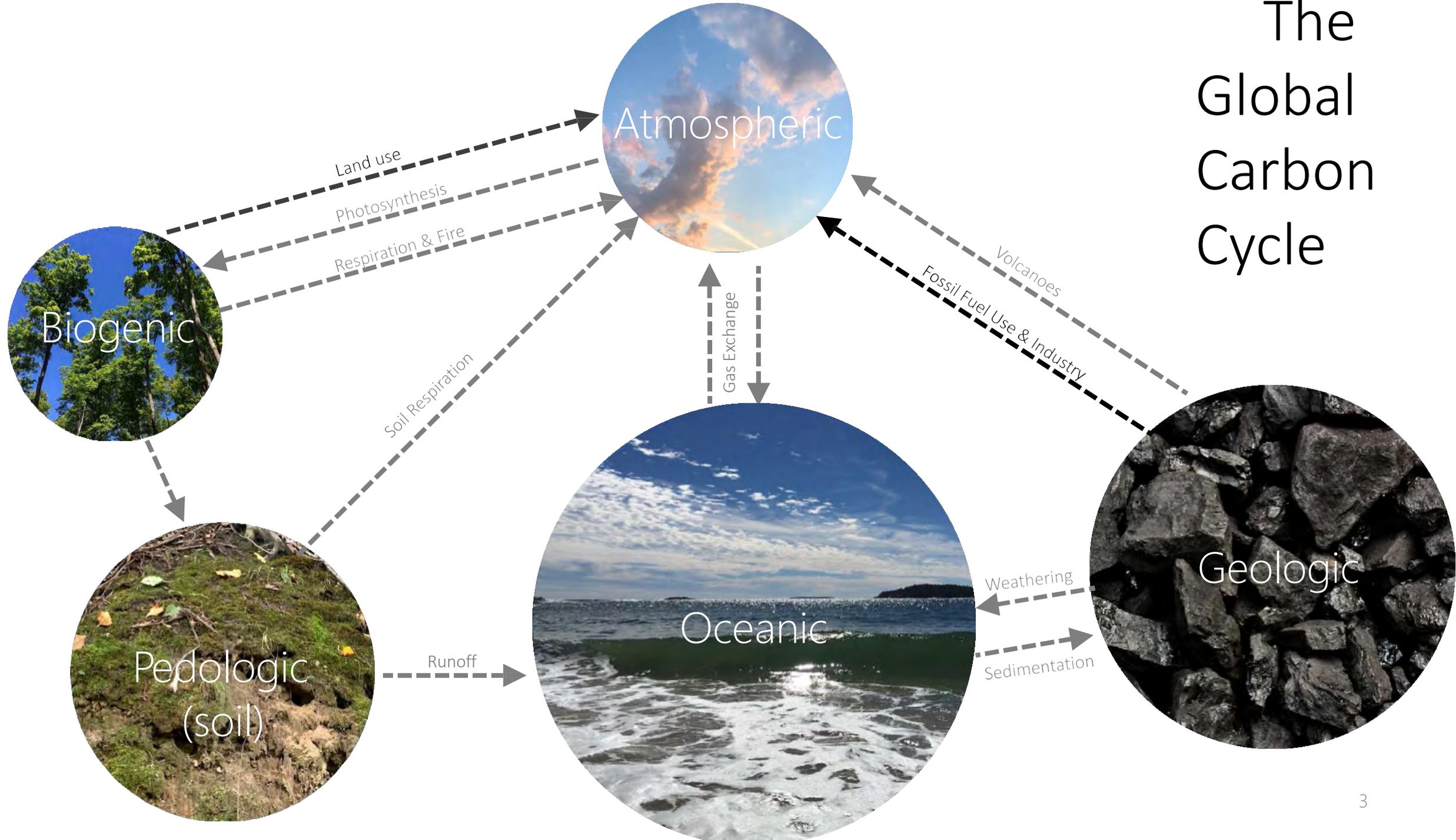
# Global Carbon stocks (carbon pools)

\*in gigatons

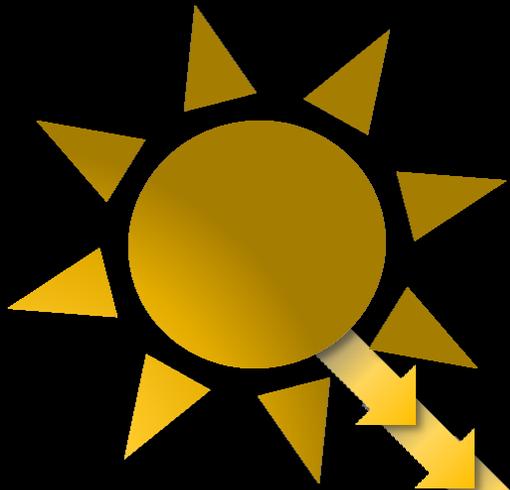


Source: Janowiak et al. 2017

# The Global Carbon Cycle

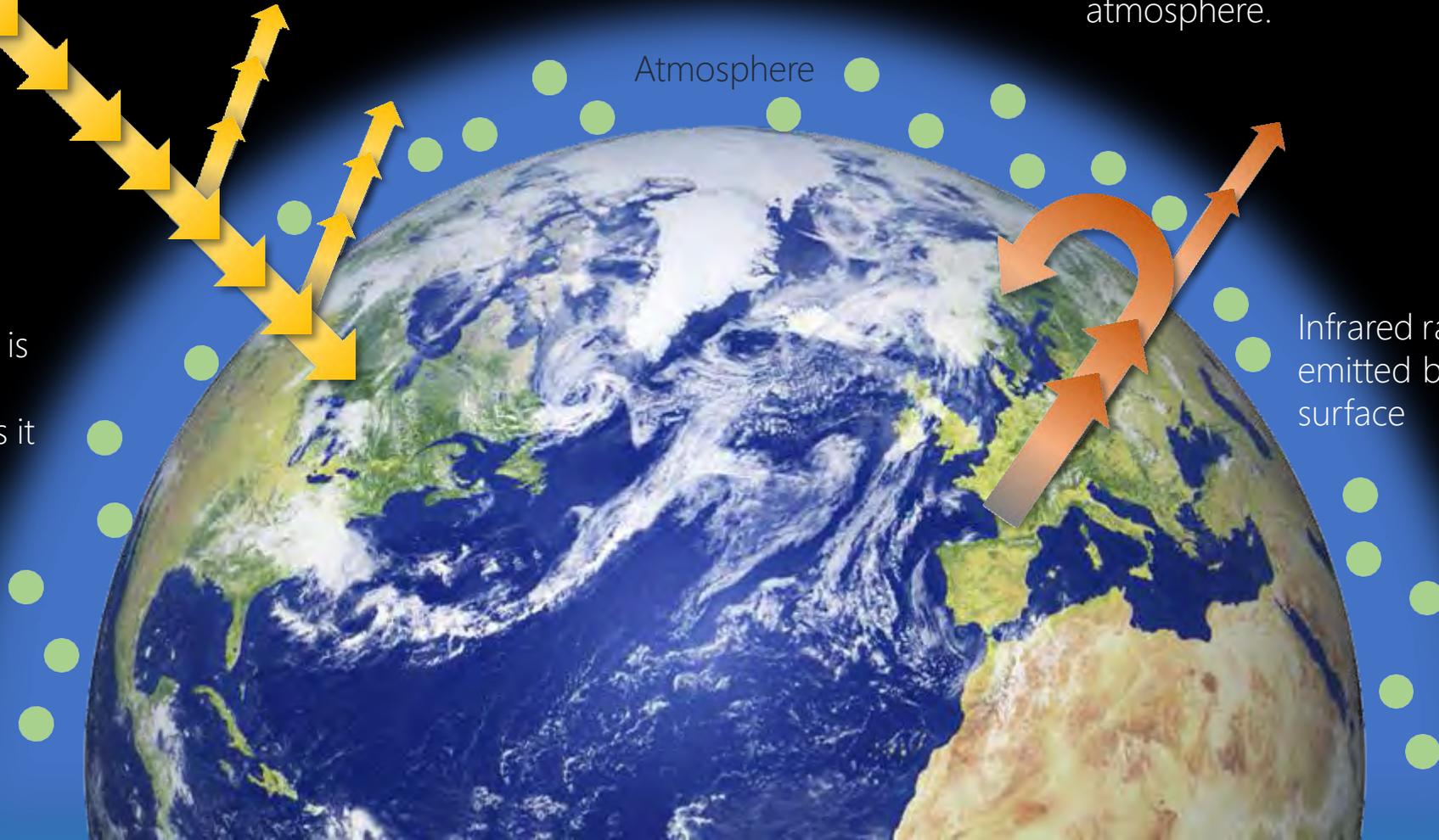


# The Greenhouse Effect



Some solar radiation is reflected by the atmosphere and Earth

Some solar radiation is absorbed by Earth's surface, which warms it

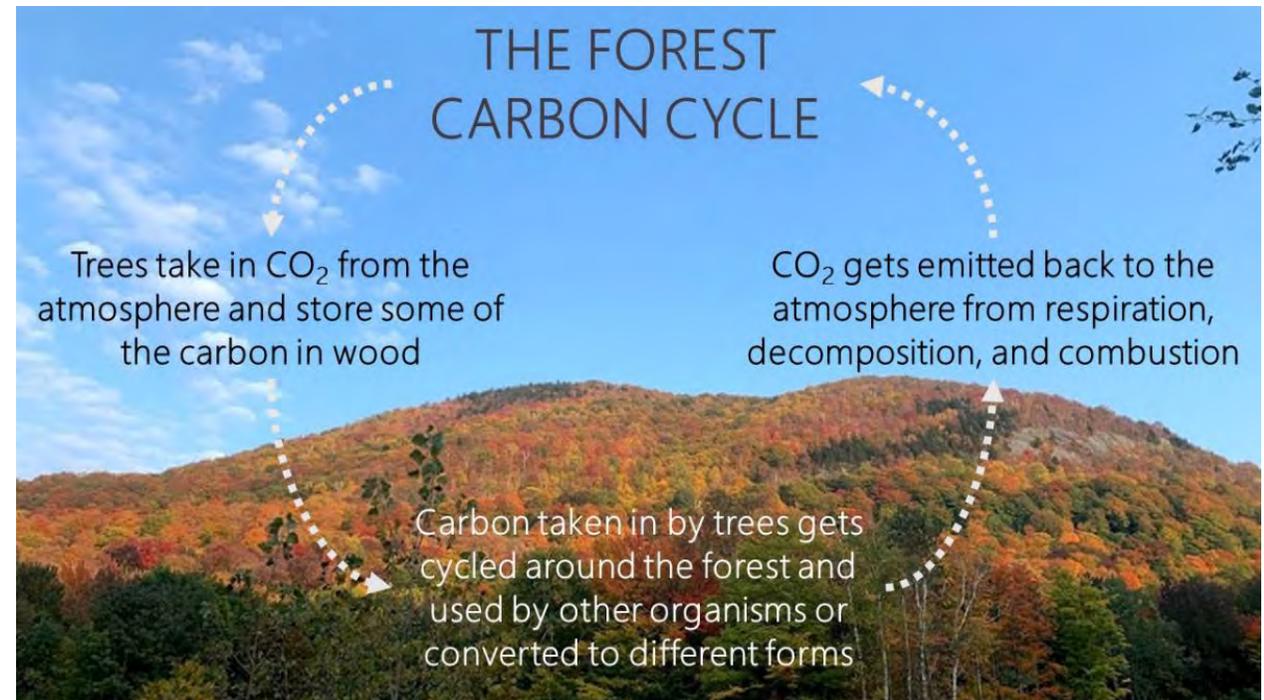
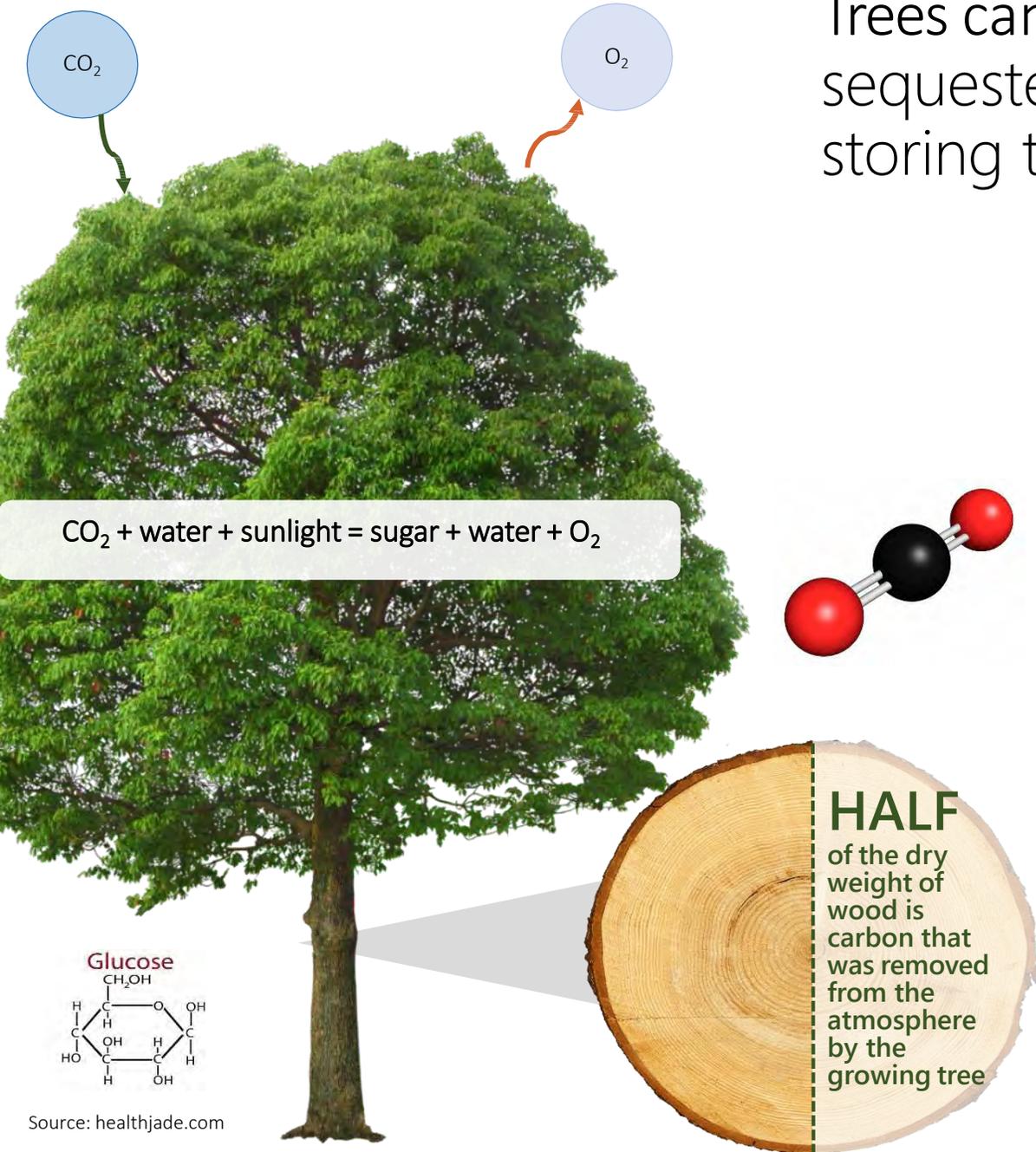


Atmosphere

Some of the infrared radiation passes through the atmosphere. Some is absorbed by greenhouse gases and then re-emitted in all directions. The effect is to warm Earth's surface and lower atmosphere.

Infrared radiation is emitted by Earth's surface

Trees can help mitigate climate change by sequestering CO<sub>2</sub> from the atmosphere and storing the carbon in wood and soil



Source: VT Dept. Forests, Parks, and Recreation

# Carbon Terminology 101

## Carbon storage

total the amount of carbon in an entity (tree, acre of forest, cord of wood)

## Carbon sequestration

the process of taking CO<sub>2</sub> from the atmosphere and storing it

## Carbon emissions

the opposite of sequestration (CO<sub>2</sub> release back to atmosphere)

Carbon sequestration + carbon emissions =  
**Carbon flux**

the change in carbon storage

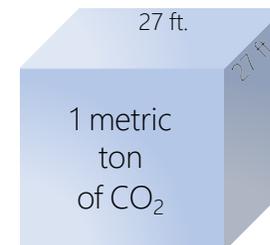
Net sequestration = carbon sink

Net emissions = carbon source

For easier comparisons, we convert carbon and other greenhouse gases to the same units = carbon dioxide equivalent (CO<sub>2</sub>e)

### Helpful conversions

1 metric ton (Mt) = 1 Mg = 1000 Kg = 2,205 lbs  
1 Mt C = 3.67 Mt carbon dioxide equivalent (CO<sub>2</sub>e)  
1 Mt C per ha = 1.49 Mt CO<sub>2</sub> per acre  
Wood is ~50% carbon by dry weight



Average car

Emits 4.75 Mt CO<sub>2</sub>e/year



Average Acre of Forest

Sequesters 1.3 Mt CO<sub>2</sub>e/year



Cord of Firewood



Contains 3.4 Mt CO<sub>2</sub>e

Forests of the Northeast store the equivalent of ~54 years of the region's current annual GHG emissions

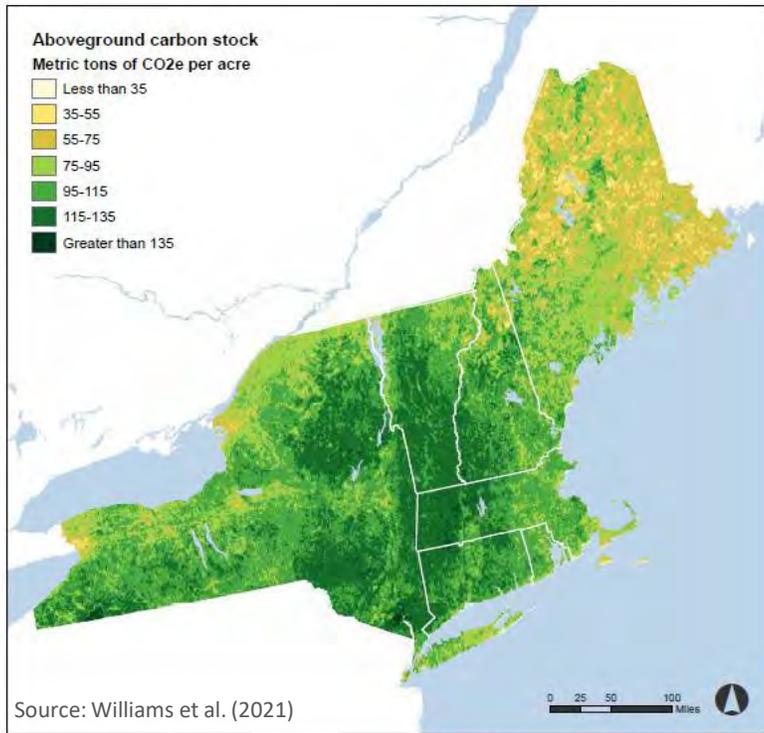
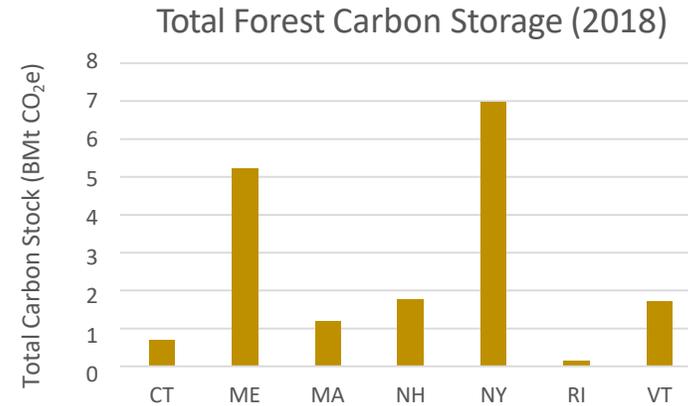
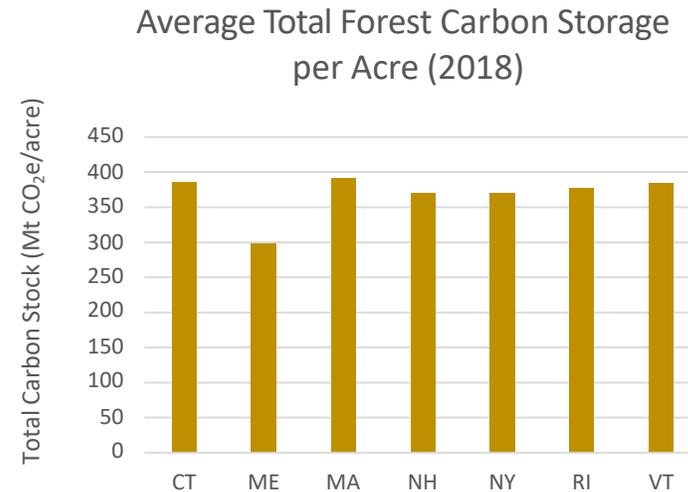


FIGURE 3. Above ground carbon stocks, expressed in metric tons of CO<sub>2</sub>e per acre, smoothed from the original dataset with focal statistics that average over a 1 km x 1 km block. The highest value in the original, 30 m resolution map is 210 metric tons of CO<sub>2</sub>e per acre.



As of 2018, the NE forests stored 17.5 billion Mt CO<sub>2</sub>e

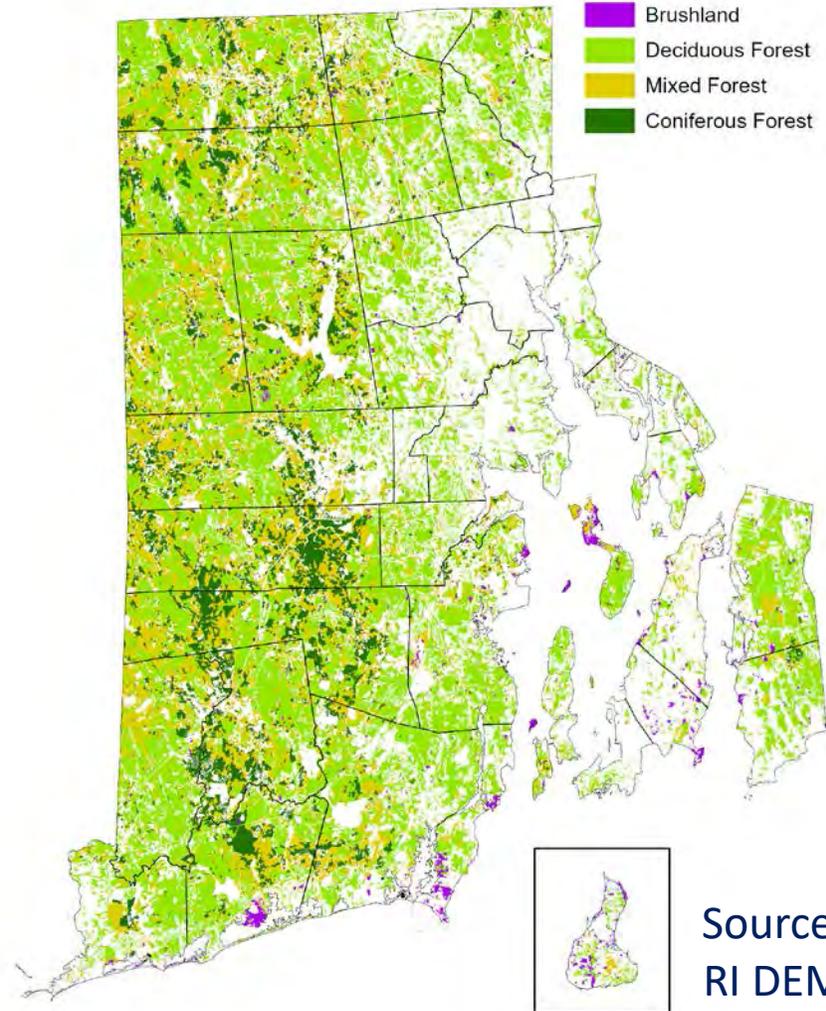


Or an average of 368 Mt CO<sub>2</sub>e/acre

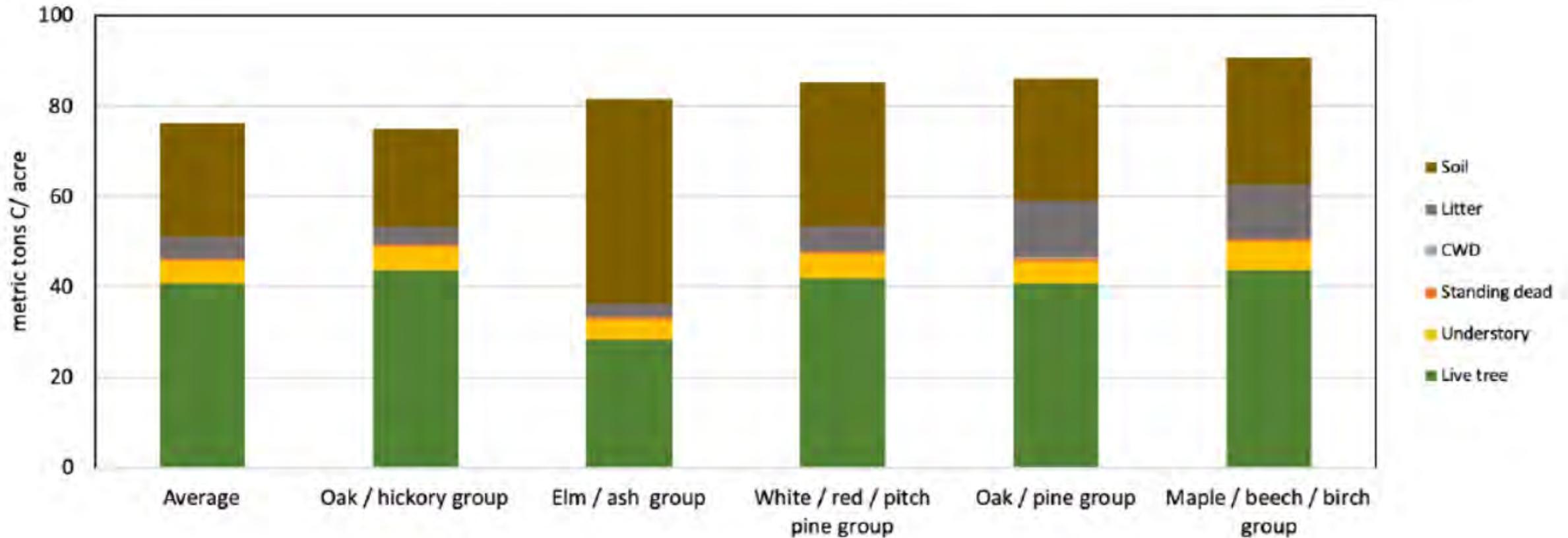
Carbon stock and flux data are for 2018, includes all forest carbon pools. Emissions data gathered per state and year varies; estimates are approximate. Carbon data source: Domke et al. 2020

# Distribution of basic RI forest types

**About 367,000 acres  
53% of land area**



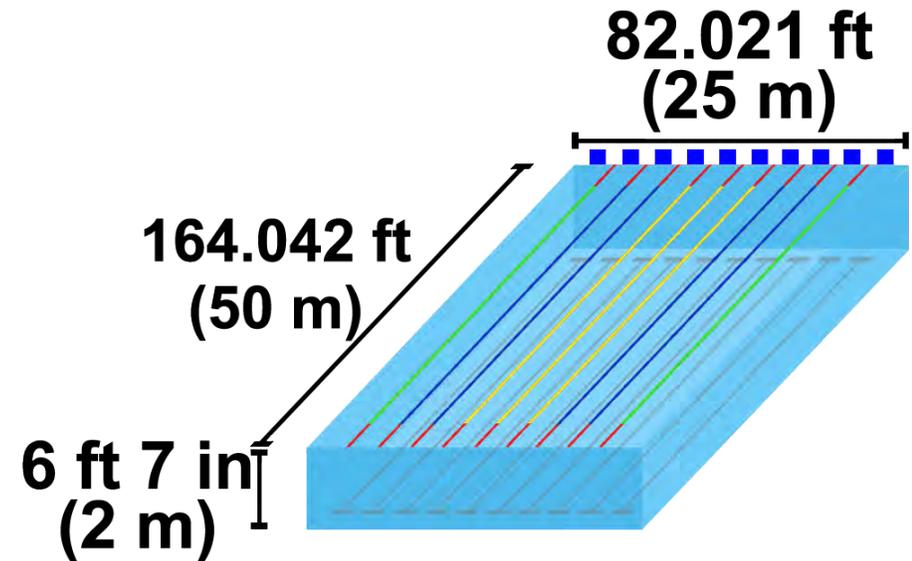
# Carbon Density of Common RI Forest Types



Average carbon storage for RI forest types = 75 metric tons/acre = 275 MT CO<sub>2</sub>e/acre

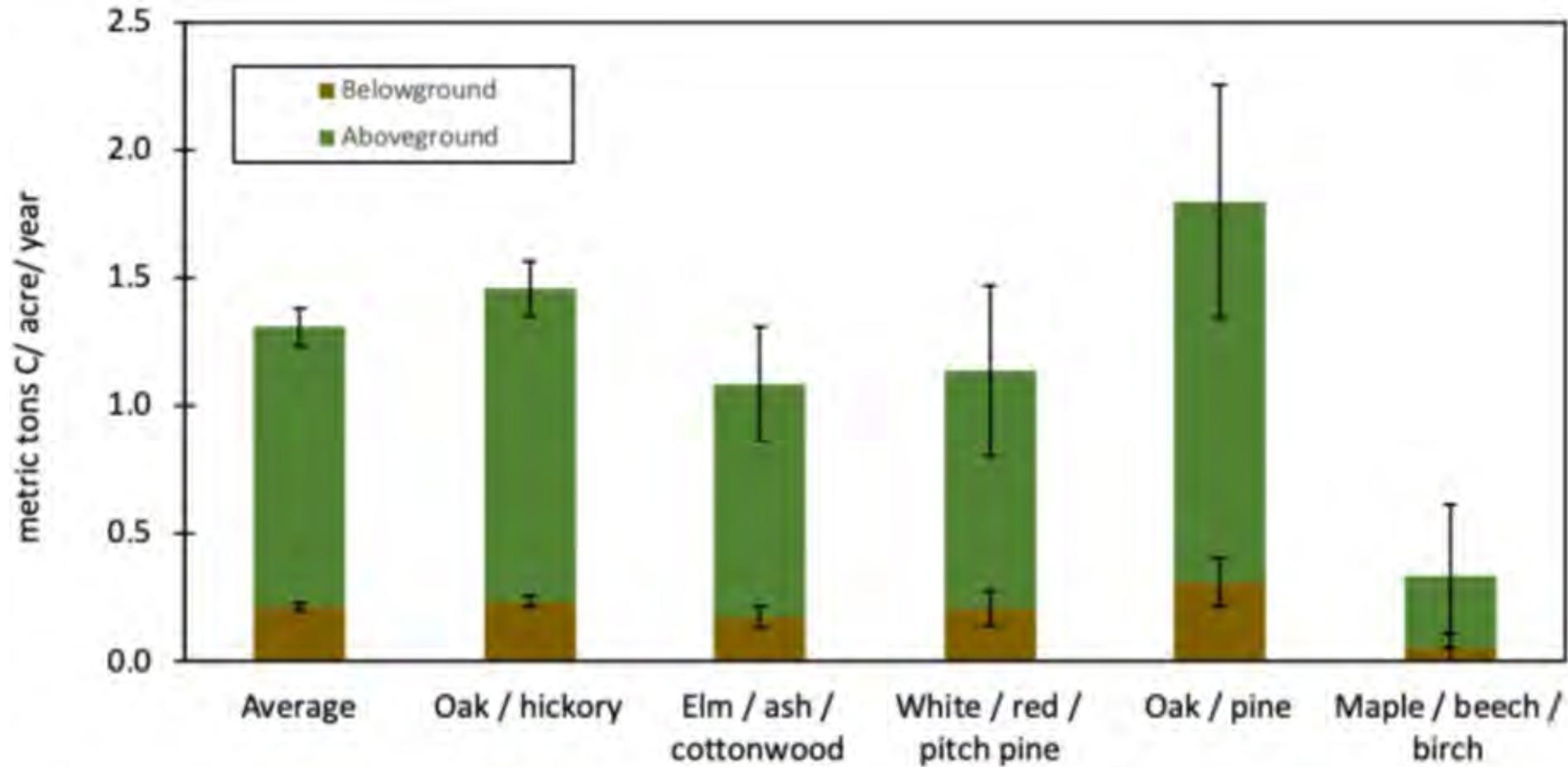
Source: FIA data

Total carbon storage of RI forests = 27 million metric tons  
= more than 3,300 Olympic swimming pools



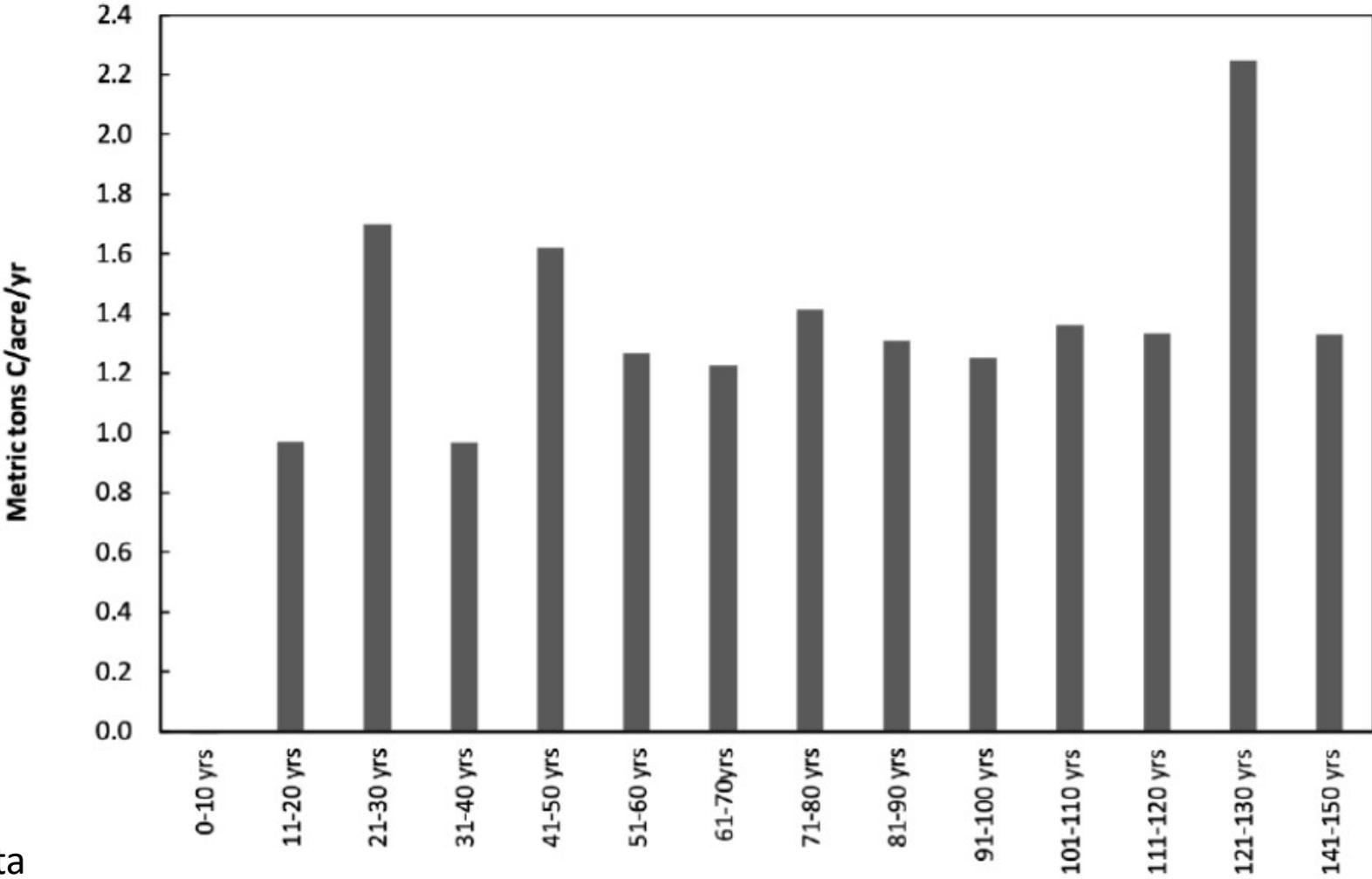
**Volume: 660,000 US gal**

# Sequestration Rates of Common RI Forest Types



Source: FIA data

# RI Forest Carbon Sequestration by Age Class

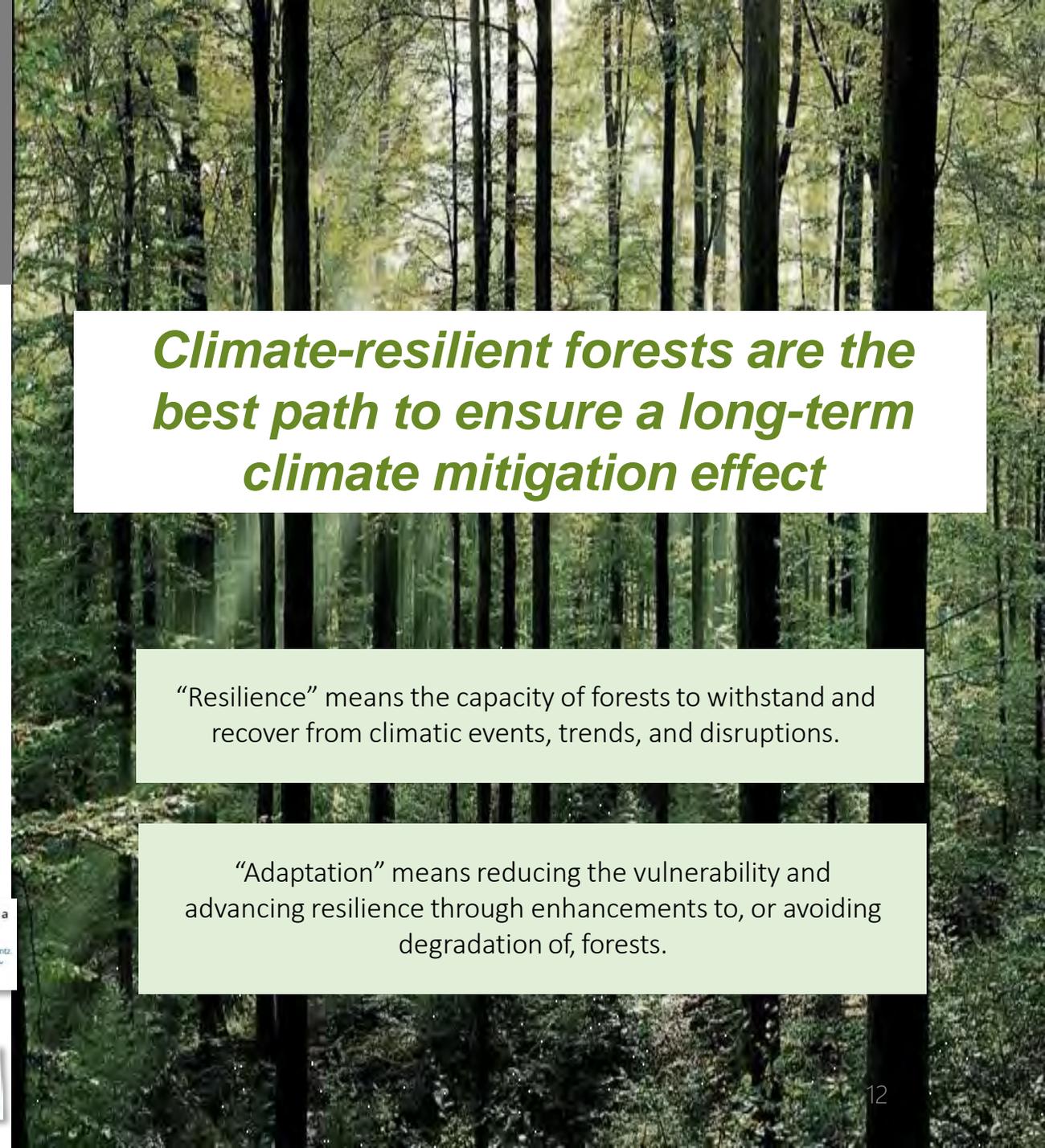


Source: FIA data

RI forests absorb nearly 500,000 metric tons of carbon each year  
= Annual emissions of 100,000 passenger vehicles



Climate change itself poses a risk to the ability of forests to sequester and store carbon, and to keep it stored for long periods of time

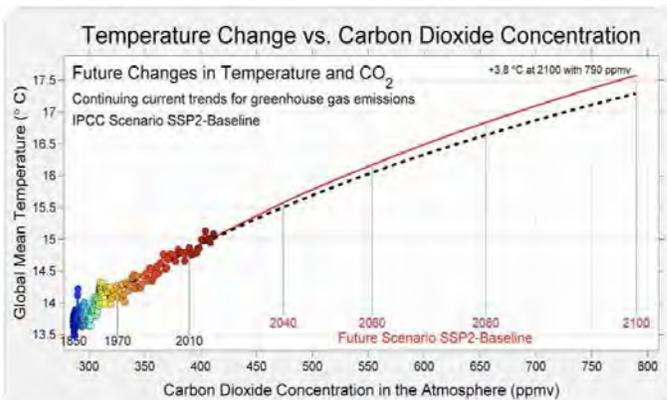


**Climate-resilient forests are the best path to ensure a long-term climate mitigation effect**

“Resilience” means the capacity of forests to withstand and recover from climatic events, trends, and disruptions.

“Adaptation” means reducing the vulnerability and advancing resilience through enhancements to, or avoiding degradation of, forests.

- Increased mortality?
- More stressors?
- Altered growth rates?
- More disturbances?
- More insects and diseases?
- Faster decomposition rates?
- Regeneration failure?



Source: Berkeley Earth

**Forest Insects and Climate Change**

Deepa S. Pureswaran, Alain Roques & Andrea Battisti  
 Current Forestry Reports 4, 35–50 (2018) | Cite this article  
 14k Accesses | 83 Citations | 72 Altmetric | Metrics

**Widespread Increase of Tree Mortality Rates in the Western United States**

Science • 23 Jan 2009 • Vol 323, Issue 5913 • pp. 521–524 • DOI:10.1126/science.1165900

A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests

Craig D. Allen, Alison K. Macalady, Haroun Chenchouni, Dominique Bachelet, Nate McDowell, Michel Vennedier, Thomas Kitzberger, Andreas Rigling, David D. Breshears, E.H. Tied Hogg, Patrick Gonzalez, Rod Fernandes, Zhen Zhang, Jorge Castro, Natalia Demidova, Jong-Hwan Lim, Gillian Allard, Steven W. Running, Neil Cobb

**Tree mortality from drought, insects, and their interactions in a changing climate**

William R. L. Anderegg, Jeffrey A. Hicke, Rosie A. Fisher, Craig D. Allen, Julianne Aukema, Barbara Benz, Jeremy W. Lichstein, Alison K. Macalady, Nate McDowell, Yude Pan... See all authors  
 09 June 2015 | https://doi.org/10.1111/nph.13477 | Citations: 312

**Climate variability drives recent tree mortality in Europe**

Mathias Neumann, Volker Mues, Adam Moreno, Hubert Hasenauer, Rupert Seidl  
 First published: 17 April 2017 | https://doi.org/10.1111/gcb.13724 | Citations: 99

**Forest disturbances under climate change**

Alfred Egler, Dominik Thom, Markus Kautz, Dick Martin, Benita Milva-Peterson, Gergely Marton, Jan Wild, Steffen Janda, Michel Per, Ada Hoesung, Michael J. Lenoir, Christoph Tolsted, David Mankin, Mircea Jucoba, Maciej Filipiak, Thomas A. Bragg, Christoph J. E. Schurr

**Unraveling the drivers of intensifying forest disturbance regimes in Europe**

Rupert Seidl, Mart-Jan Schelhaas, Manfred J. Lexer  
 First published: 26 April 2011 | https://doi.org/10.1111/j.1365-2486.2011.02452.x | Citations: 361

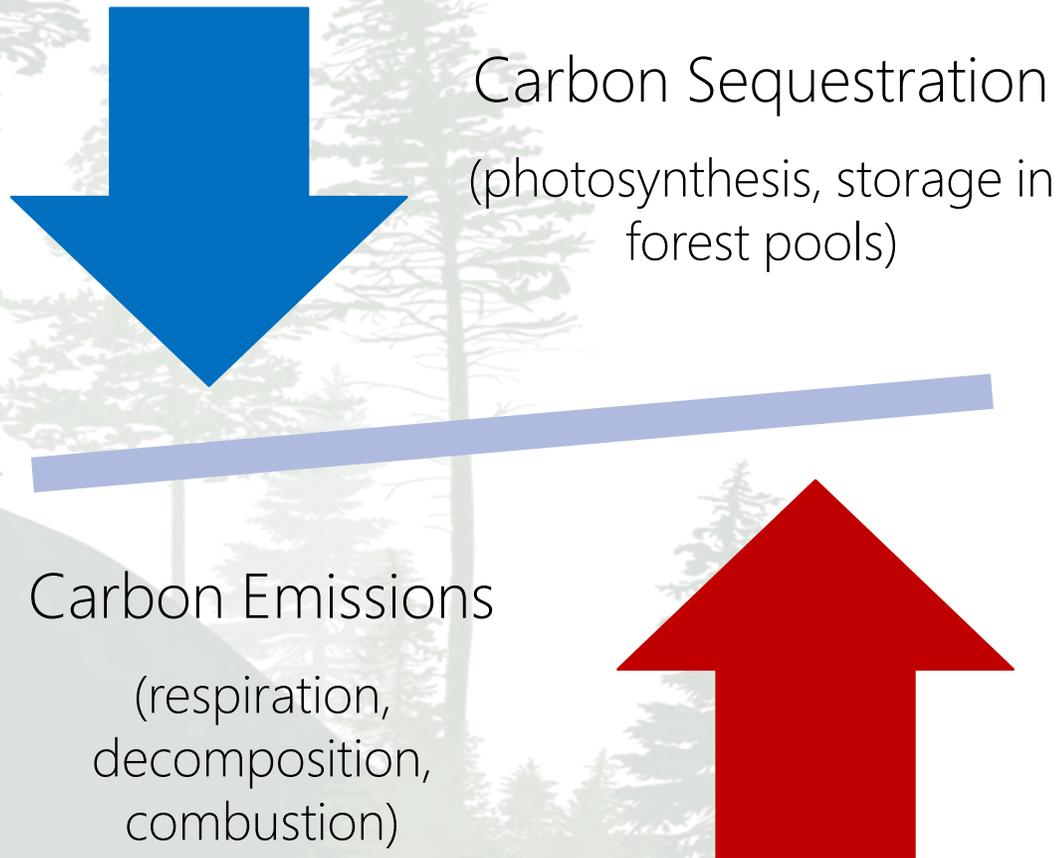
**Climatic stress increases forest fire severity across the western United States**

Adam M. Larson, Jonathan C. B. Nesmith, MaryBeth Keifer, Eric C. Knapp, Alan Flint, Lorraine Flint  
 22 July 2013 | https://doi.org/10.1111/rle.12151 | Citations: 129

**Hemlock Declines Rapidly with Hemlock Woolly Adelgid Infestation: Impacts on the Carbon Cycle of Southern Appalachian Forests**

April E. Hovick, Dana Worsham, Charles E. Bond, Stephen A. Hobbie, James M. Vose, & Scott D. Kipphut

# Whether a forest is a sink or source of carbon depends on the balance between uptake and release



## CLIMATE FACTORS

- Moisture
- Temperature
- Length of growing season

## SITE FACTORS

- Nutrients, light, water
- Soil characteristics
- Tree density
- Natural disturbances, timber harvests
- Elevation, slope direction

## TREE FACTORS

- Species, genetics
- Age, size
- Health and condition



Not all forest stands are carbon sinks

Carbon sink

Sequestration > Emissions

Carbon source

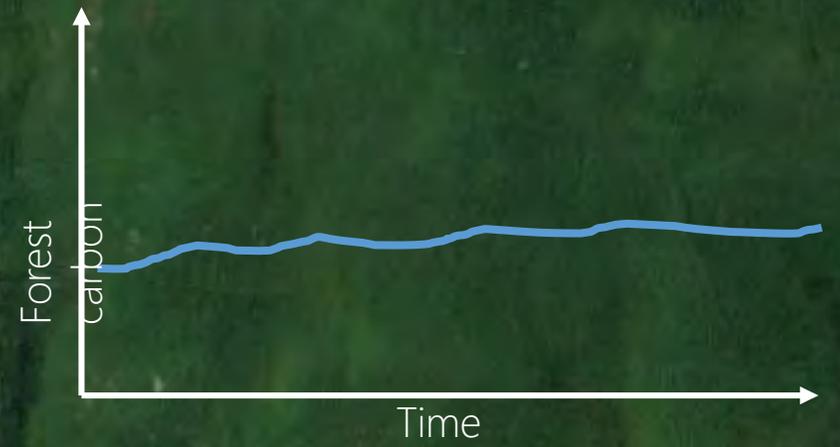
Sequestration < Emissions



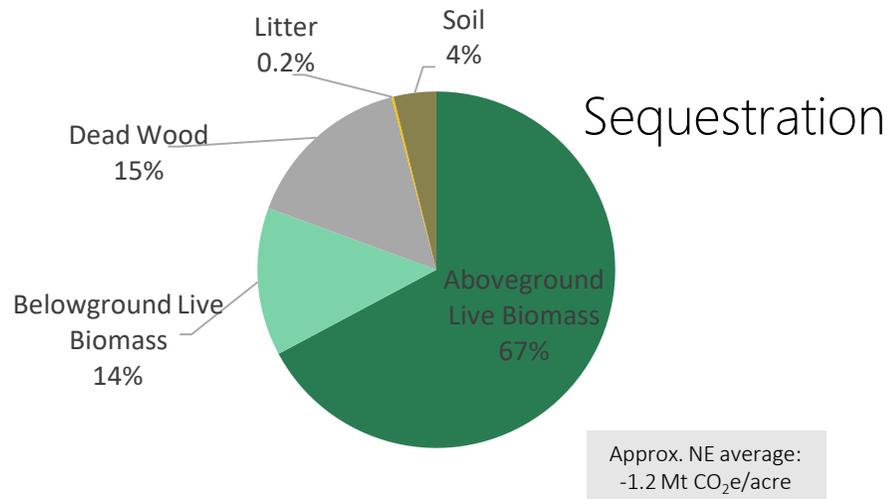
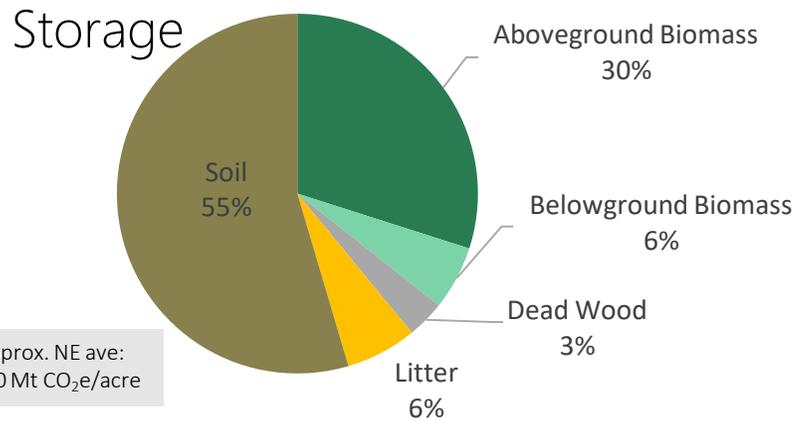
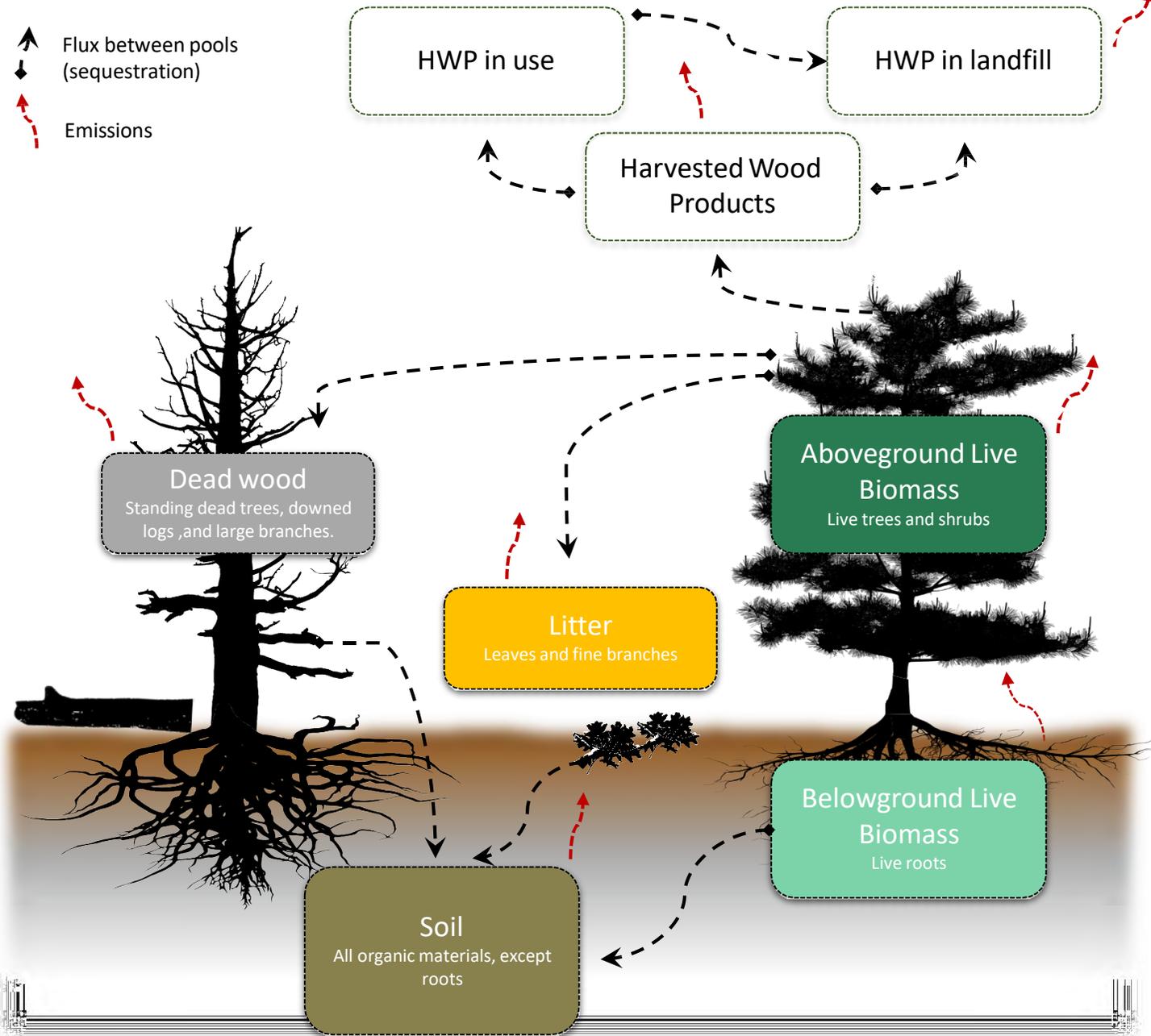
# Stand



# Landscape

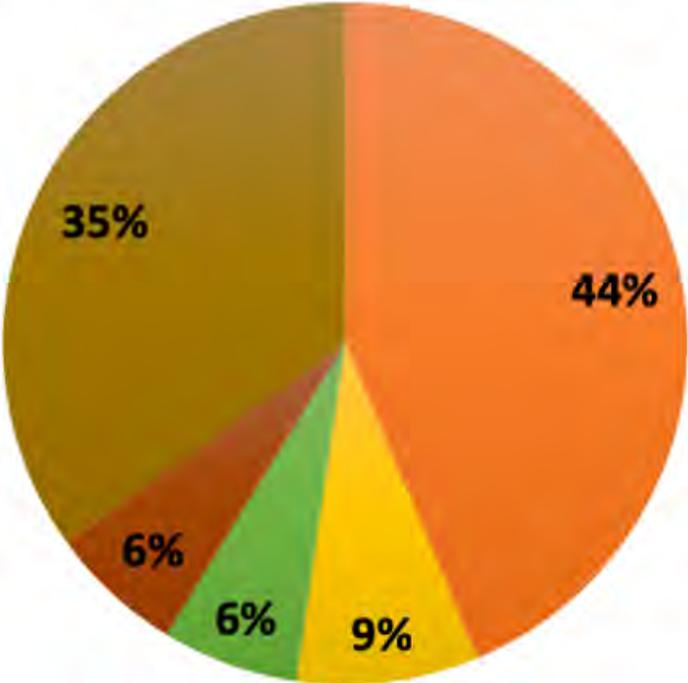


# Forest carbon pools



Data source: Domke et al. (2020)

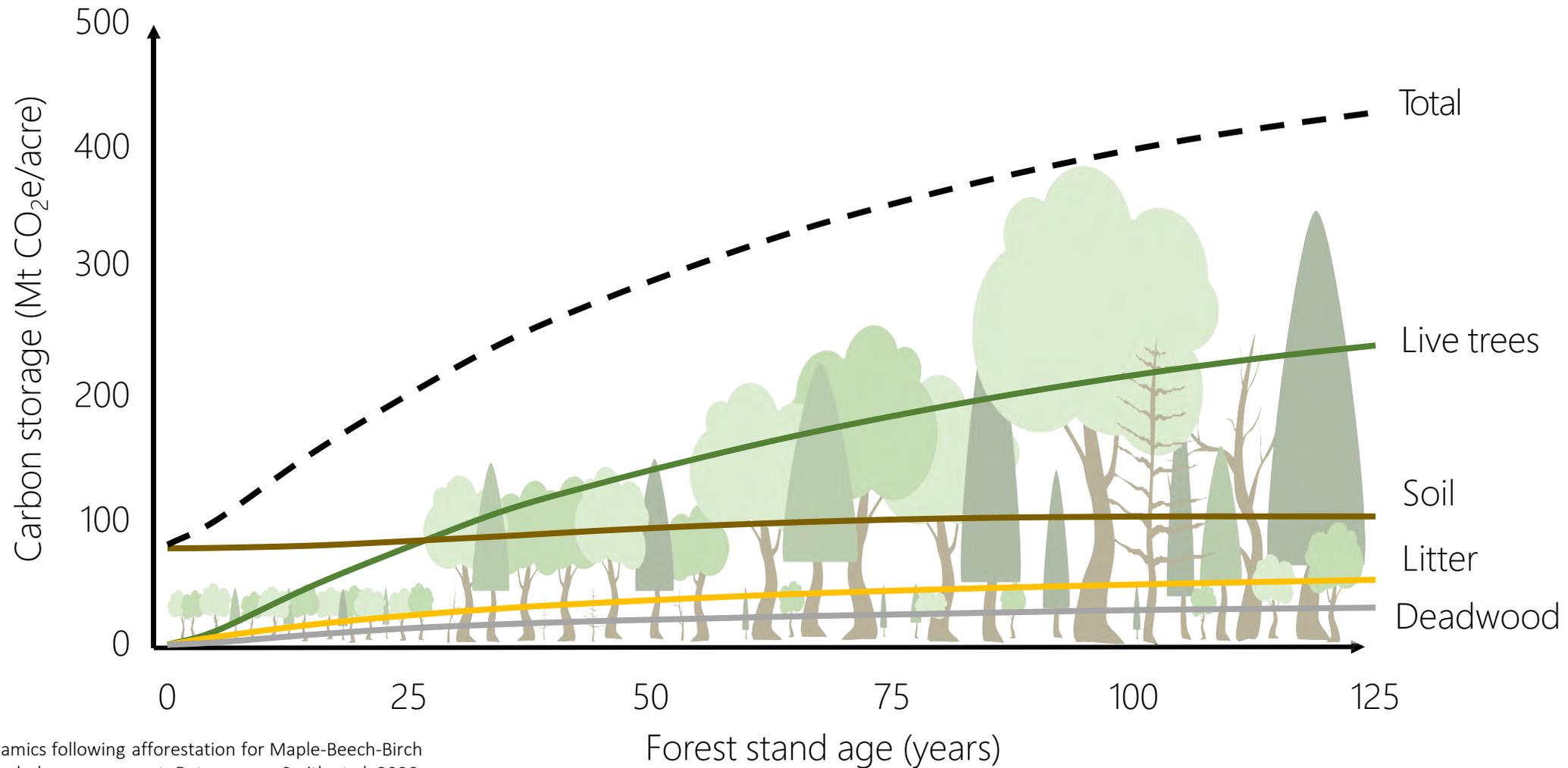
### RI FOREST CARBON STORAGE (FIA DATA)



- Live Aboveground
- Live Belowground
- Dead Wood
- Litter
- Soil Organic

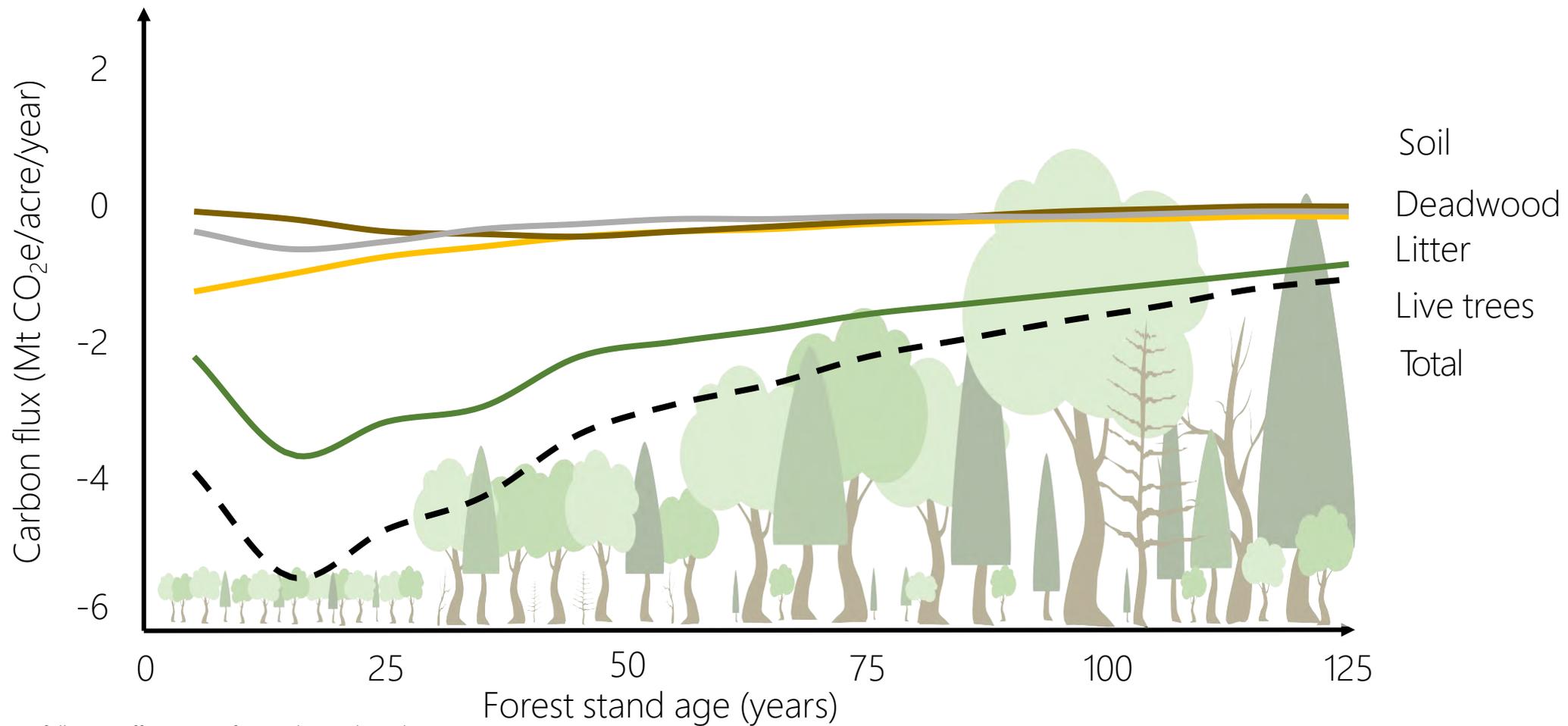
**Where the carbon is found in RI forests**

# Carbon storage varies over forest stand development



Note: carbon dynamics following afforestation for Maple-Beech-Birch forest, does not include management. Data source: Smith et al. 2006.

# Carbon sequestration varies over forest stand development

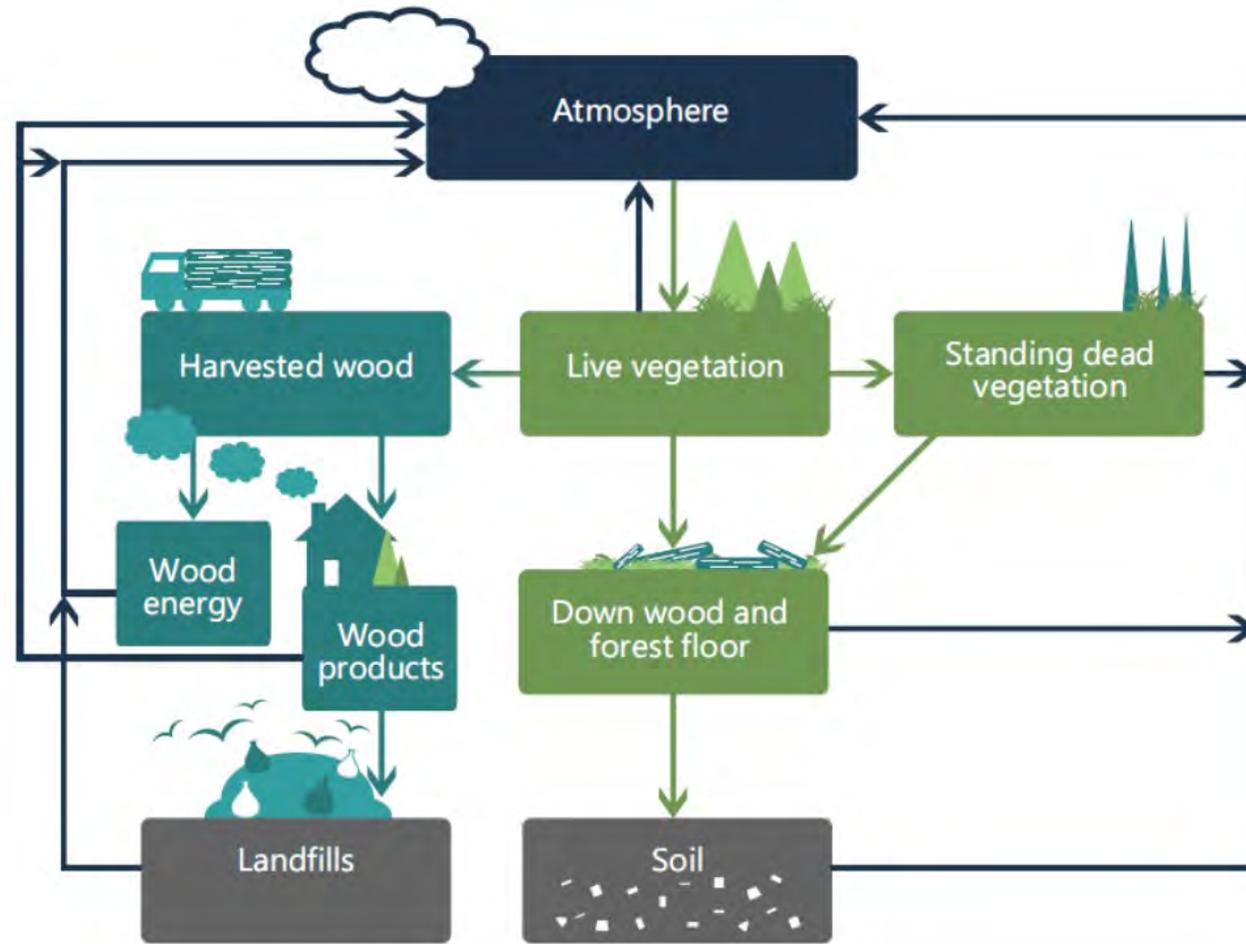


Note: carbon dynamics following afforestation for Maple-Beech-Birch forest, does not include management. Data source: Smith et al. 2006.

# Summary Points: Carbon Science

- ❖ For forests to help mitigate climate change, consider '*what does the atmosphere see?*'
- ❖ Carbon moves in and out of forest pools and the atmosphere
- ❖ Live trees account for ~75% of sequestration
- ❖ Carbon is difficult to quantify, especially changes in non-tree pools
- ❖ Management decisions have the most influence on live trees, dead wood, and harvested wood products
- ❖ Soils and leaf litter are most influenced by reducing potential losses

# All land use decisions impact forest carbon

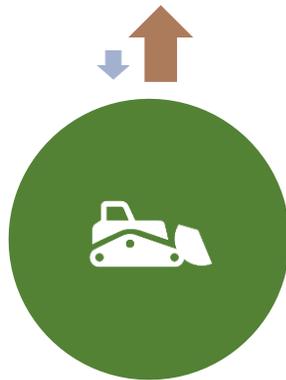


## Reduce sources of carbon emissions

**Keep carbon in the forest** and avoid CO<sub>2</sub> emissions into the atmosphere

## Enhance the forest carbon sink

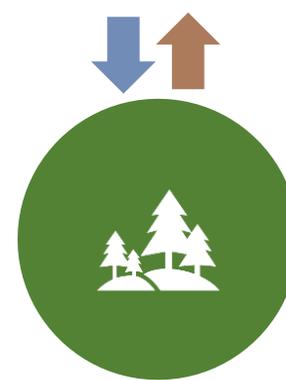
**Increase carbon storage through active sequestration** of atmospheric CO<sub>2</sub> and storage in carbon pools



Limit forest conversion to other land uses



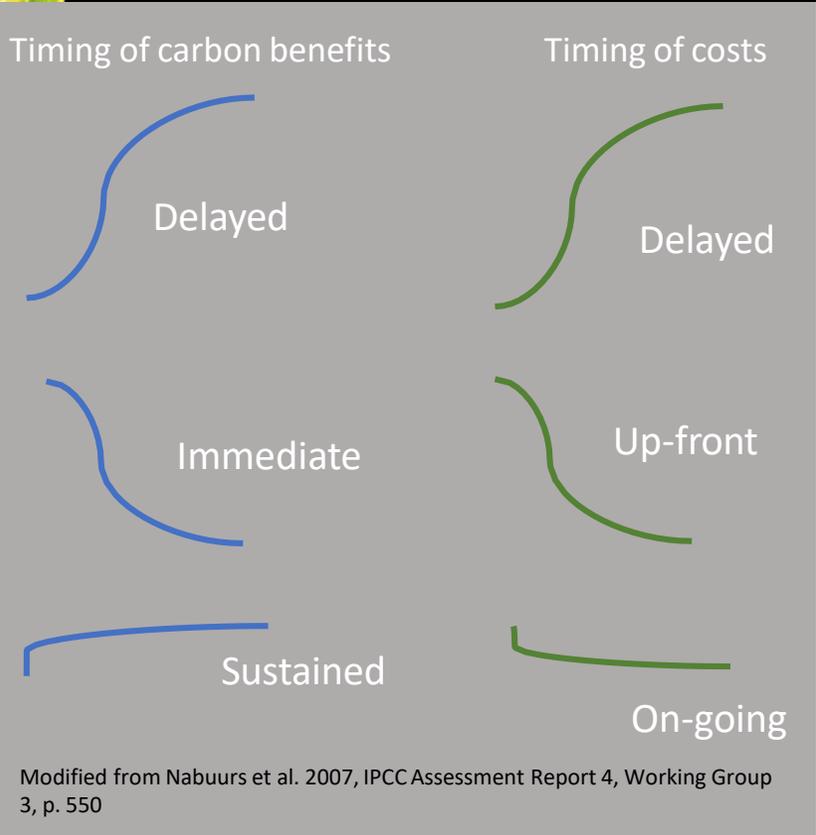
Plant trees where they are lacking



Manage forests to maintain or increase carbon



Substitute wood for high GHG products (concrete, steel, plastics, fossil fuels, etc.)



# Key Concepts of Forest Carbon Management

- Timing of carbon benefits and costs can vary
- Can increase, decrease or sustain carbon pool
- Can alter future rate of change (flux)
- Management can happen at multiple scales
- Actions must align with management objectives of site and landowner's risk tolerance
- Nothing is guaranteed

A photograph of a forest with tall, thin trees and a forest floor covered in fallen branches and green undergrowth. The text "A quick tour of some carbon-friendly forest management practices..." is overlaid in white on the image.

A quick tour of some carbon-friendly forest management practices...

# Avoid forest loss



- Forest conversion is biggest loss of forest carbon benefits
- Results in substantial emissions
- Also, loss of potential future sequestration and other forest benefits

# Establish reserves

- Passive or non-extractive management
- Can occur across many scales:
  - property
  - part of property,
  - stand
  - groups
- May or may not be permanently conserved



# Grow trees for a longer time before harvest



- Increase the time between harvests to grow larger trees
- Recommendations typically suggest an additional 5-15 years

# Use Thinning to Improve Growth of Remaining Trees

- Reduce competition for light and other resources
- For carbon, sources recommend removing less than 25% of volume over 20 years



# Increase Proportion of Younger Age Classes



- Promote regeneration with different harvesting techniques
- Capitalize on fast growth of young trees
- Recommendations are for 5-15% of stand, <20% over 20-year period
- Uneven-aged management generally results in higher carbon stocks than even-aged
- Will result in a temporary loss of carbon (emissions) until young trees have occupied new space

# Increase Structural Complexity

- Increase size/age class diversity across stands, include gaps and skips, large trees, tip-ups, cavities and other features
- Emulate natural disturbances (windstorms etc.)



# Retain Big Trees



- Large trees disproportionately contribute to forest carbon stocks
- Legacy tree retention, crop tree release, or longer cutting cycles
- A source of future deadwood

# Increase the Amount of Dead Wood

- Keep snags, create snags, and consider future snags/DWD, create more downed wood by felling and leaving
- Consider a range of size classes (larger is better), species and conditions
- Leave as many tops as possible



# Increase Forest Stocking



- Especially where stocking is low or forest cover is lacking

# Increase Species Diversity

- More species in a stand can result in higher carbon stocks because more niches are filled
- Consider “functional diversity” (trees with different strategies, like conifers vs broadleaf, different shade tolerances)



Maintaining conifer component in hardwood stands

# Plan Harvests to Retain Quality Trees and Limit Damage



Source: scenicriversfarmforest.com

- Carefully plan harvests to reduce damage to remaining trees, which can reduce their carbon sequestration rate and storage if decay and rot are introduced
- Healthy, productive forests are best for both storage and sequestration

# Protect Soil and Leaf Litter

- Soil carbon builds very slowly, but can be easily disturbed
- Following BMPs to protect soil and water also protects soil carbon
- Deadwood can protect both, and may help build soil carbon over long-term



# Tradeoffs to consider

Some birds, including Chestnut-sided warblers, require early-successional forest



Source: William H. Majoros

- Storage vs. sequestration
- Mitigation vs. resilience
- Early successional wildlife habitat
- Income needs
- Market conditions
- Impacts here vs. elsewhere

# Leakage

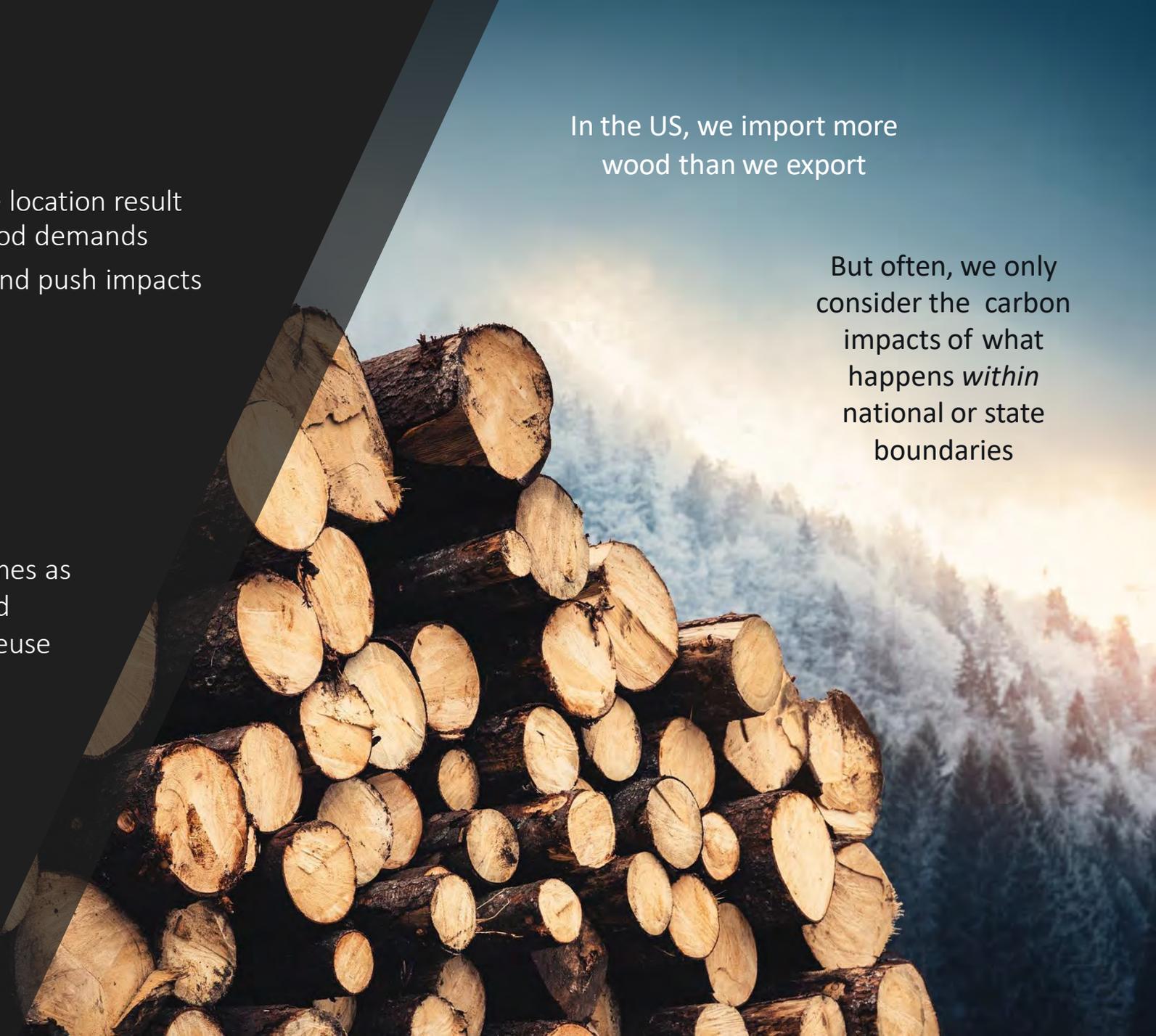
- When reductions in timber harvested in one location result in increased harvests elsewhere to meet wood demands
- Can negate intended climate benefits here and push impacts elsewhere

## *What can we do?*

- Try to maintain sustainable harvest volumes as a community until we can decrease wood consumption, increase wood recycling/reuse
- Will require a broad initiative

In the US, we import more wood than we export

But often, we only consider the carbon impacts of what happens *within* national or state boundaries



# Tradeoffs to Consider

*Forests provide many essential benefits, including carbon, but not always in equal proportion. Choosing a strategy for your forest may mean that some benefits are enhanced while others are reduced.*

- Catanzaro and D'Amato. 2019 Forest Carbon:  
An Essential Natural Solution for Climate Change

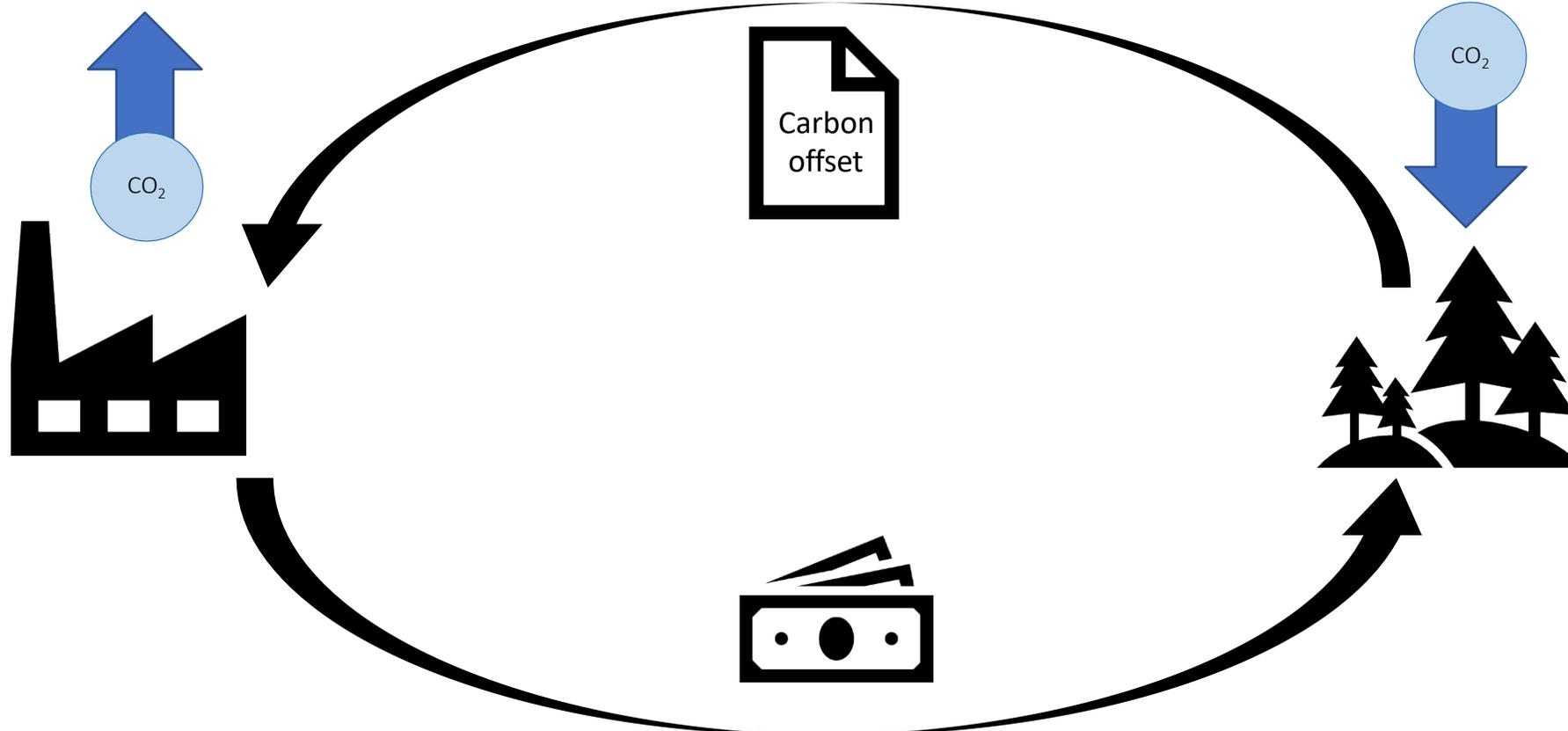
# Summary Points: Forest Carbon Management

- All management decisions (or lack of) affect forest carbon
- Keeping forests as forests is the most important action we can take
- Also important to manage for the impacts of climate change
- Consider your goals and possible tradeoffs
- Work with a forester to evaluate forest carbon outcomes
- Traditional conservation-minded forestry practices are often examples of carbon-friendly forestry

# What is the purpose of forest carbon offsets?

Allows entities to reduce emissions more quickly than they could otherwise by purchasing offsets where carbon is actively being sequestered or emissions avoided

Helps to finance forest management, restoration, conservation, tree planting, and other activities



# Two Types of Carbon Markets

- Required by law in some states
- Regulated transaction of offsets
- Centralized market, registry, and standard
- Set offset price
- Emitters are required to reduce their emissions but can either buy allowances from other regulated emitters or carbon offsets
- Allowances decline over time for gradual reductions in emissions



The Regional Greenhouse Gas Initiative  
an initiative of Eastern States of the US

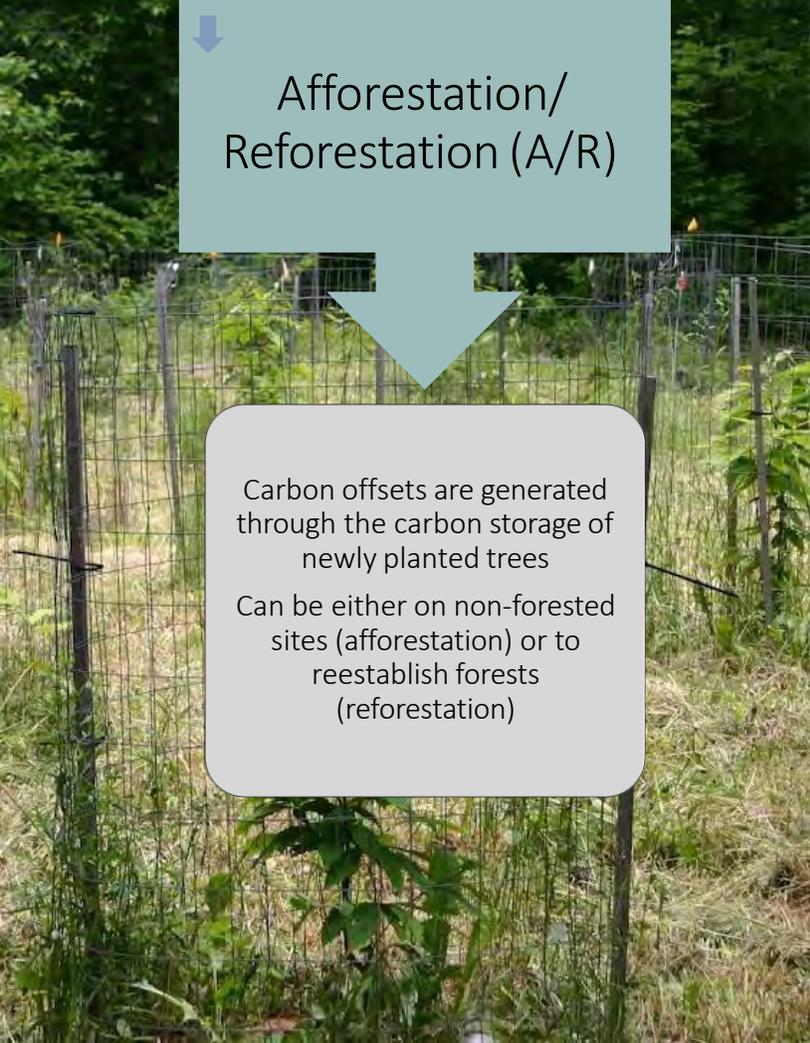
Forest offsets are allowed, but to date, no enrolled forest projects



- Not required by law
- Not regulated
- No centralized market or registry
- No requirement for the use of a registry or standard
- No set offset price, depends on what buyers will pay
- Open to everyone: individuals, companies
- No requirement for buyers to reduce emissions over time

# Three current categories for forest carbon offsets

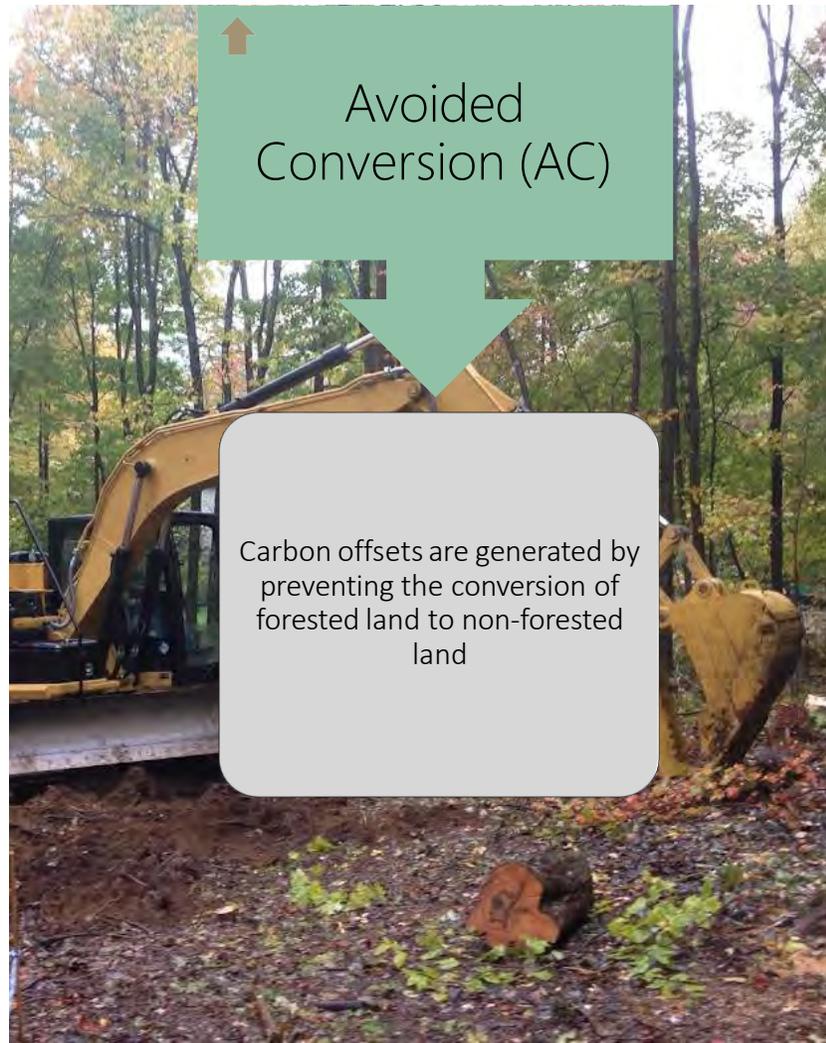
1



Afforestation/  
Reforestation (A/R)

Carbon offsets are generated through the carbon storage of newly planted trees  
Can be either on non-forested sites (afforestation) or to reestablish forests (reforestation)

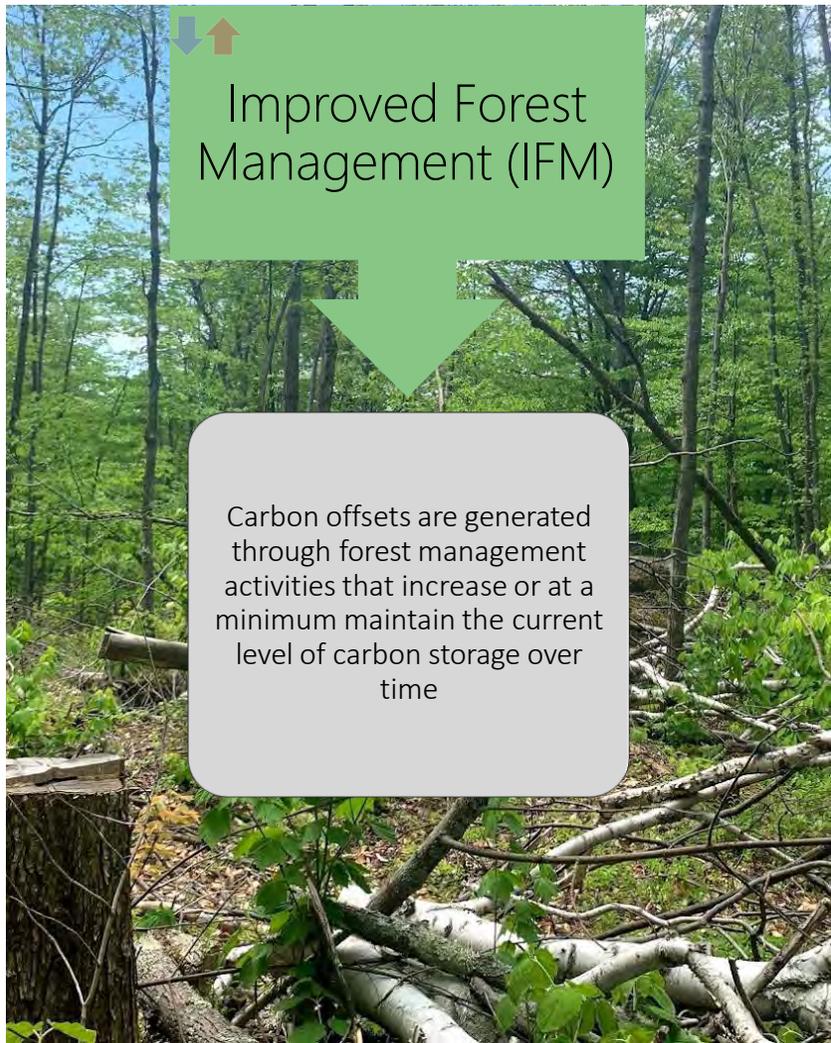
2



Avoided  
Conversion (AC)

Carbon offsets are generated by preventing the conversion of forested land to non-forested land

3



Improved Forest  
Management (IFM)

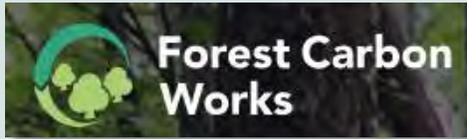
Carbon offsets are generated through forest management activities that increase or at a minimum maintain the current level of carbon storage over time

# Smaller properties under 2,000 acres (like most of those in RI)



- Until recently, shut out of carbon markets because of lack of financial feasibility
- Two pathways:
  - Aggregation (multiple landowners in one project)
  - New programs that aim to reduce inventory and transaction costs
- Mostly voluntary market
- Small-to-modest payments

# Current Offset Programs for Smaller Landowners



## Forest Carbon Works

- 40+ acres
- 100-year commitment (CA compliance market)
- Similar to large project, but reduces costs with inventory approach



## CORE Carbon (Finite Carbon)

- 40-5,000 acres
- 40-year commitment
- Use FIA plots and sub-sampling to reduce costs



## Family Forest Carbon Program

- Payment for carbon-friendly forest management practices
- 30 - 2,400 acres
- 20-year commitment
- Monitors practices on each property; carbon on a sub-set, compare to FIA
- Awaiting acceptance in VCS registry
- Plan to launch in some parts of NE region this spring



## NCX: Natural Capital Exchange

- 1-year deferred harvest, unique methods
- 'Harvest deferral credits' = % of a traditional offset
- No acreage threshold
- 1-year commitment
- Independent marketplace for buying/selling credits, awaiting acceptance in VSC registry

# Make sure you understand before entering a program!

Example questions you may want to ask before entering a carbon program

What types of management activities are allowed?
How is verification done?
Does the contract stay with the property if I sell?
What happens if I need to exit the contract early?
What happens if there is a natural disturbance on the property?
Is salvage harvesting allowed?
Are harvest wood product carbon stocks included?
What happens if the developer goes bankrupt or ceases to exist?
What is the payment schedule?
What is the expected revenue for my land?
How do you assure the integrity of carbon offsets?
Who buys the offsets?



# There is currently a lot of debate over carbon offsets, which likely means that they will continue to evolve...



## **A Nonprofit Promised to Preserve Wildlife. Then It Made Millions Claiming It Could Cut Down Trees.**

The Massachusetts Audubon Society has managed its land as wildlife habitat for years. Here's how the carbon credits it sold may have fueled climate change.

## **Systematic over-crediting in California's forest carbon offsets program**

Grayson Badgley, Jeremy Freeman, Joseph J. Hamman, Barbara Haya, Anna T. Trugman, William R.L. Anderegg, Danny Cullenward  
doi: <https://doi.org/10.1101/2021.04.28.441870>

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## **The U.S. Is About to Go All in on Paying Farmers and Foresters to Trap Carbon**

The problem is, it's unclear if "Carbon Offsets" even work

1. These Trees Are Not What They Seem: [www.bloomberg.com/](http://www.bloomberg.com/)
2. A Nonprofit Promised to Preserve Wildlife. Then It Made Millions Claiming It Could Cut Down Trees: [www.propublica.org/](http://www.propublica.org/)
3. The U.S. Is About to Go All in on Paying Farmers and Foresters to Trap Carbon: [www.rollingstone.com](http://www.rollingstone.com)
4. Rethinking Forest Carbon Offsets: [www.caryinstitute.org/](http://www.caryinstitute.org/)
5. Systematic Over-crediting in California's Forest Carbon Offsets Program: [www.biorxiv.org/](http://www.biorxiv.org/)
6. A Critique of NCX's Carbon Accounting Methods: [www.carbonplan.org/](http://www.carbonplan.org/)
7. A Framework to Ensure that Voluntary Carbon Markets Will Truly Help Combat Climate Change: [www.brookings.edu/](http://www.brookings.edu/)
8. The Forest for the Carbon: <http://outsideinradio.org/>



# Summary Points: Carbon Markets

- Carbon offsets are intended to help reduce emissions over time, and can help fund forest management and restoration
- Options for landowners to sell forest carbon are growing rapidly, but there are still a lot of unknowns
- Carbon offset programs can be difficult to navigate and understand
- There are a lot of benefits to trading carbon offsets, but it could bring big changes
- Carbon markets/programs will continue to evolve

A close-up photograph of a tree trunk cross-section, showing concentric growth rings in shades of brown and tan. A small, dark, irregular hole is visible in the lower-left quadrant of the image.

THANK YOU  
QUESTIONS?

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