



THE UNIVERSITY OF VERMONT  
**EXTENSION**  
FORESTRY

A quick intro to  
**Forest Carbon**

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## Carbon Sequestration

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

(via photosynthesis and transfer to other pools)

## Carbon Storage

total the amount of carbon in an entity

(e.g., tree, acre of forest, cord of wood)

## Carbon Emissions

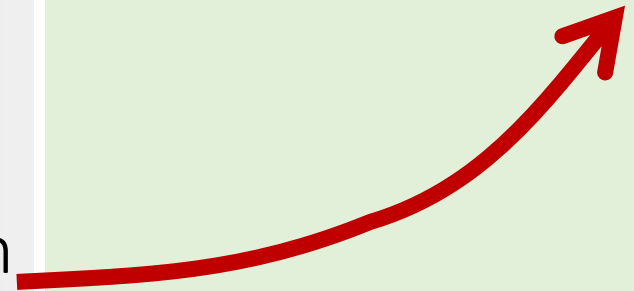
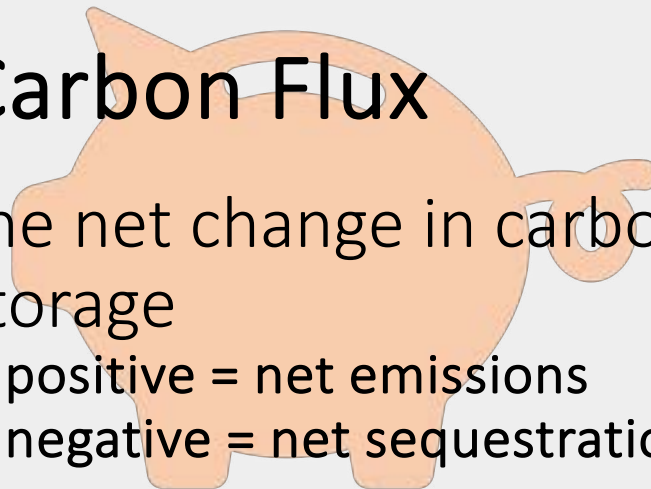
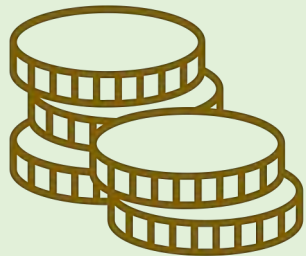
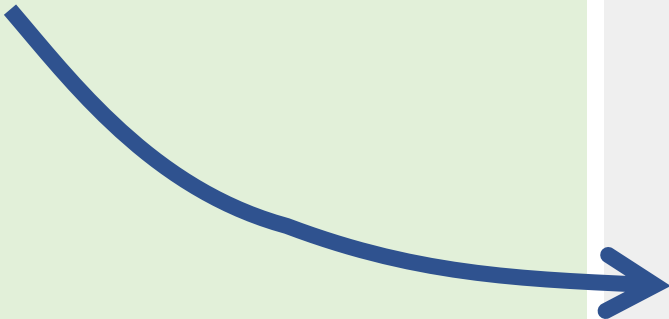
the process of releasing CO<sub>2</sub> back to the atmosphere

(via respiration, decomposition, combustion)

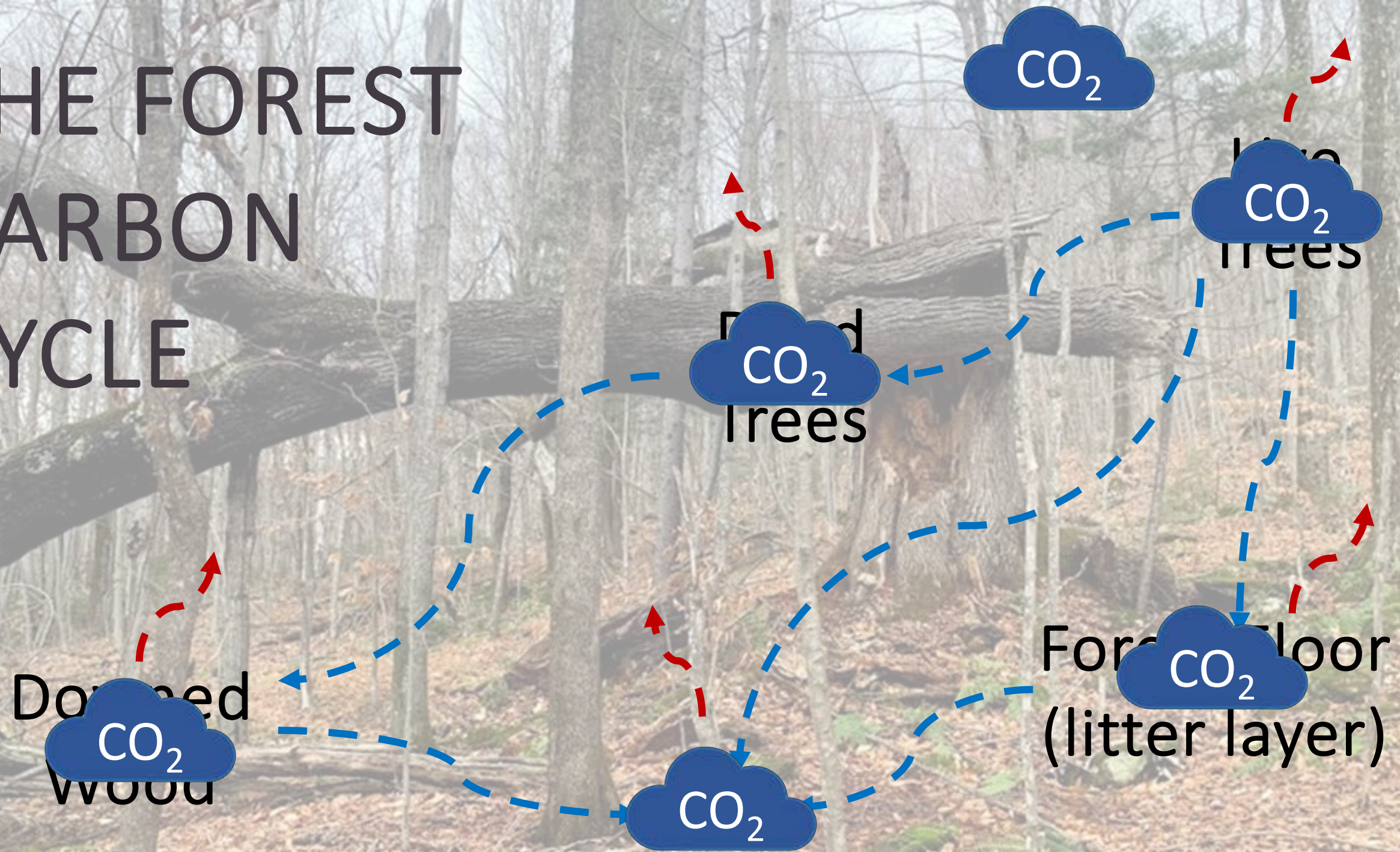
## Carbon Flux

the net change in carbon storage

- positive = net emissions
- negative = net sequestration



# THE FOREST CARBON CYCLE



# The amount of carbon sequestration, and whether a forest is a carbon sink or source, depends on many factors



**Sequestration and  
transfer of carbon to  
other pools**



**Respiration,  
decomposition,  
combustion**  
*(carbon emissions)*



Affected by:

SITE CHARACTERISTICS  
TREE CHARACTERISTICS  
MANAGEMENT  
DISTURBANCES  
STRESSORS  
CLIMATE

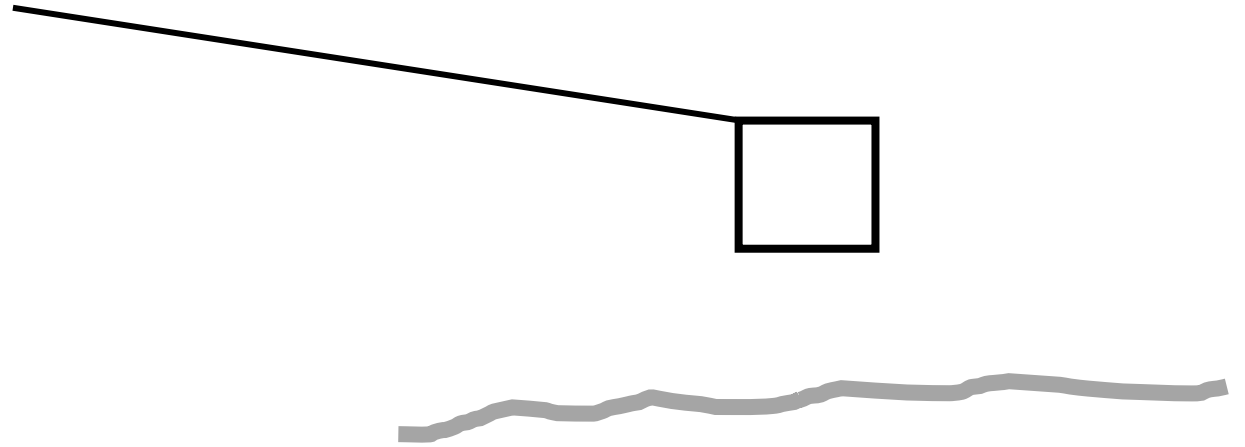
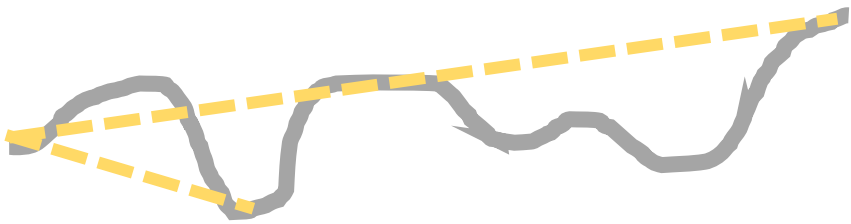
**Carbon sink = net absorber of CO<sub>2</sub>**

Sequestration > Emissions

**Carbon source = net emitter of CO<sub>2</sub>**

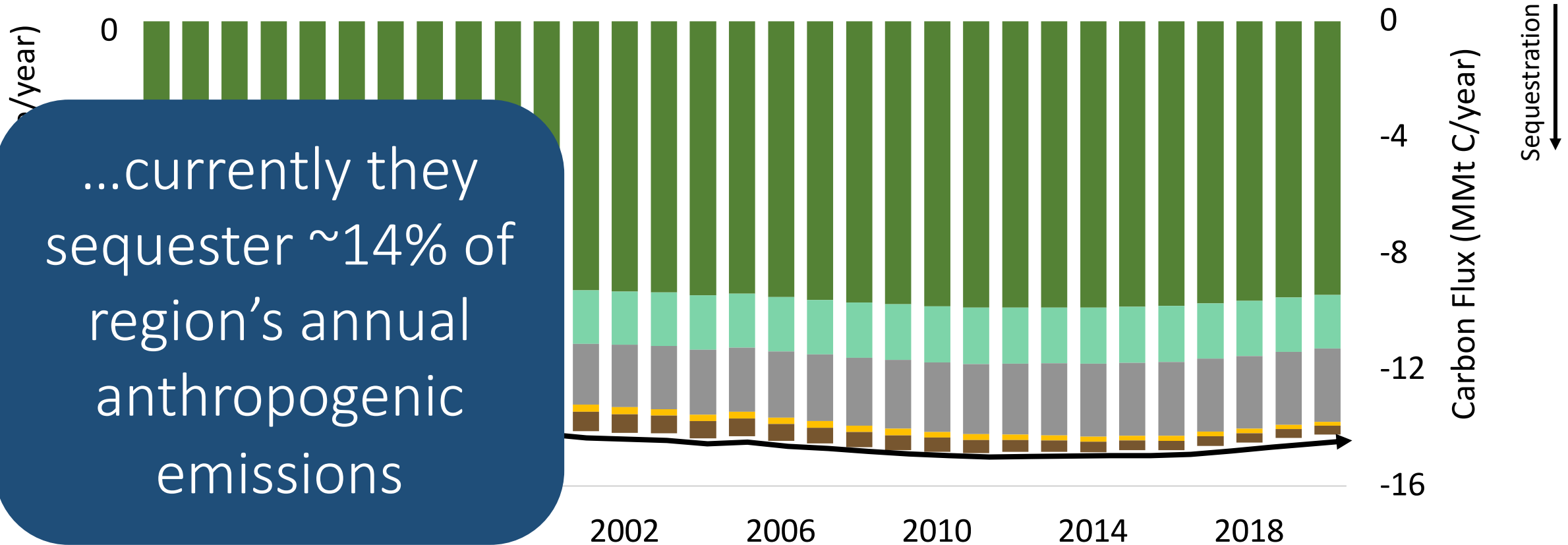
Sequestration < Emissions

# The importance of time and scale

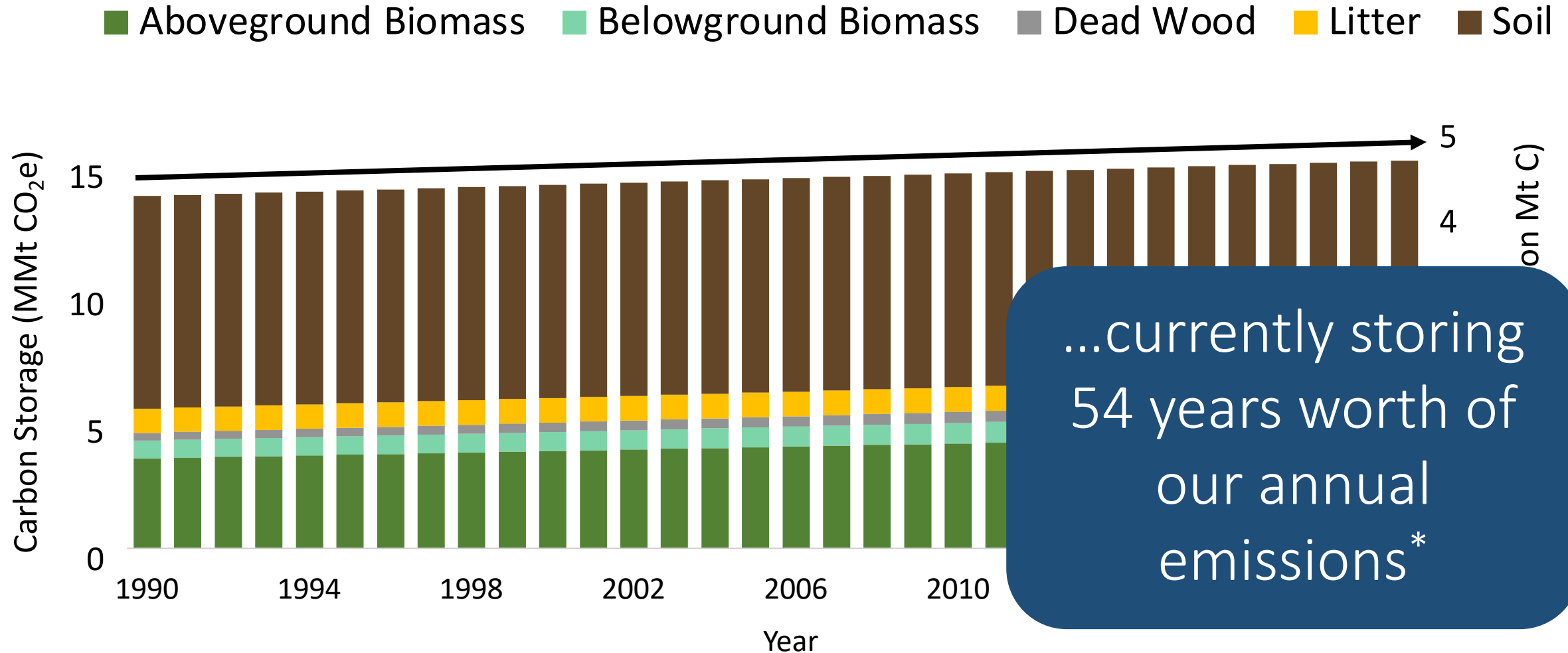


# The region's forests are a carbon sink

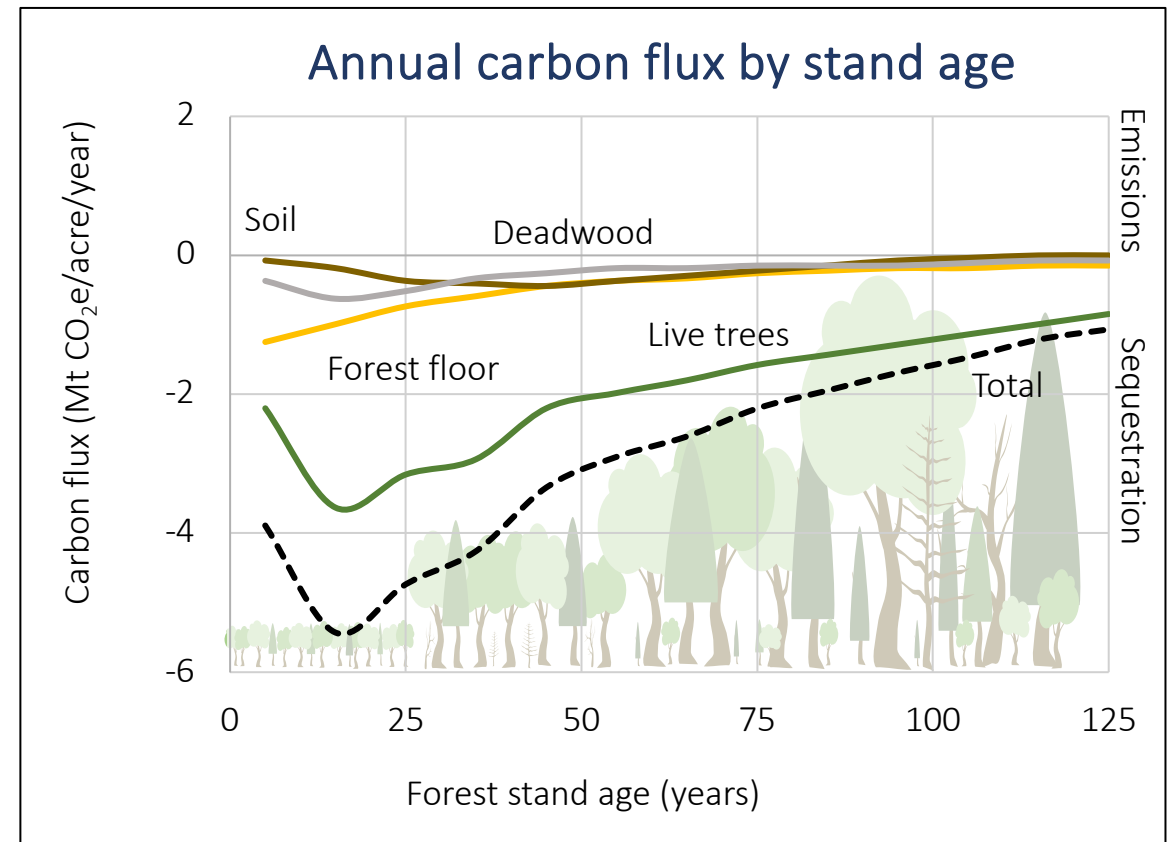
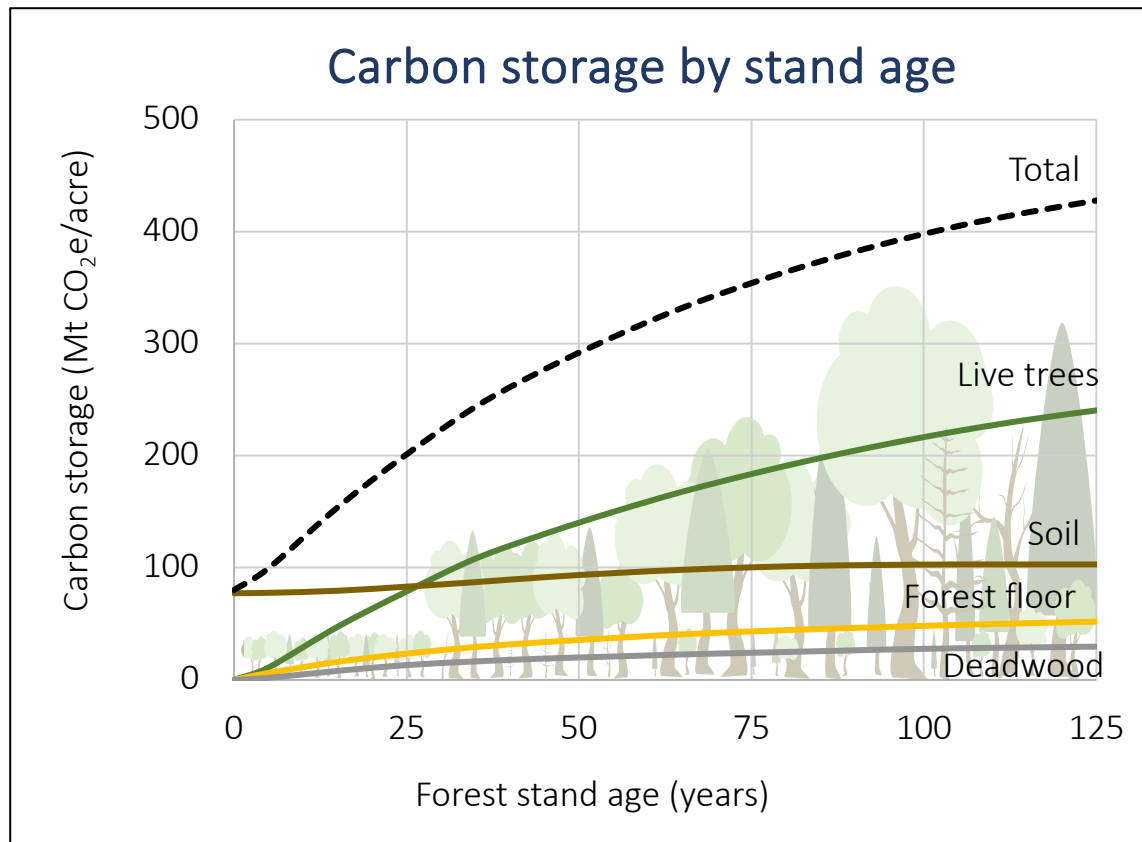
■ Aboveground Biomass ■ Belowground Biomass ■ Dead Wood ■ Litter ■ Soil



# Over time, the region's forests are storing more carbon

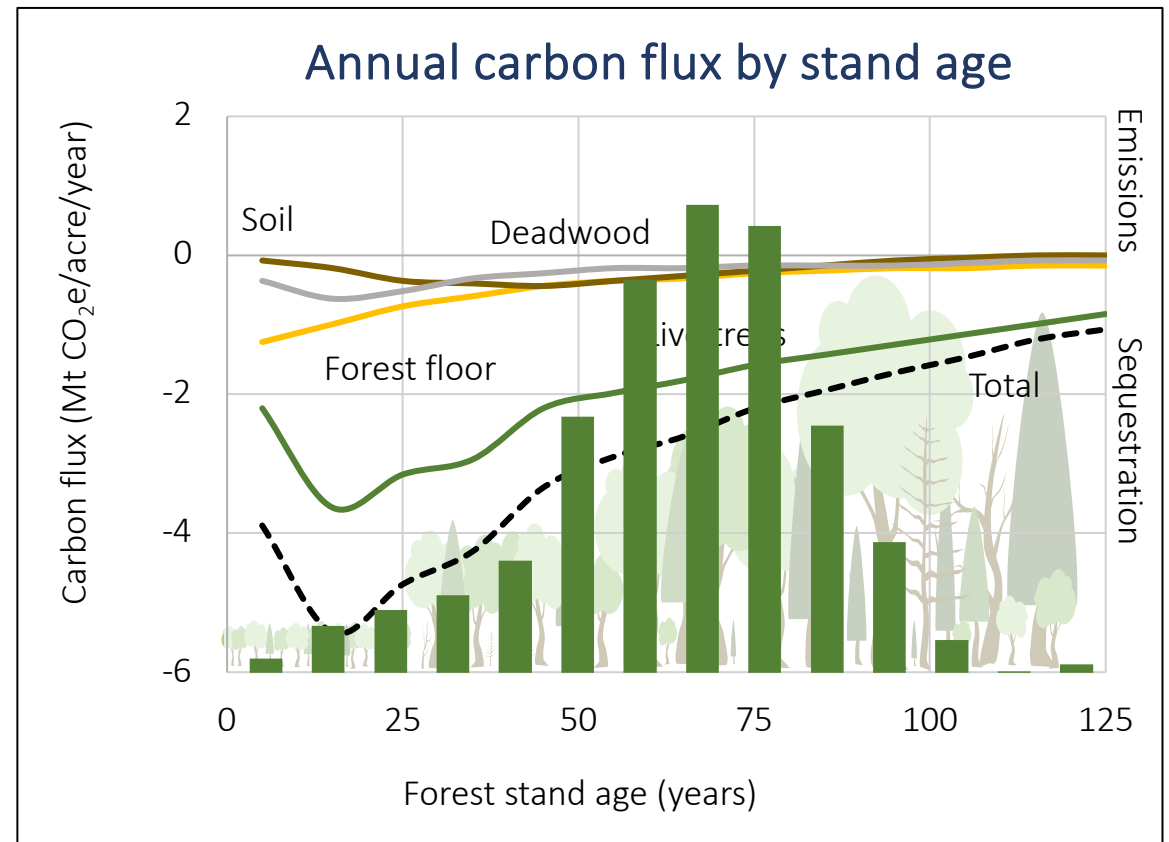
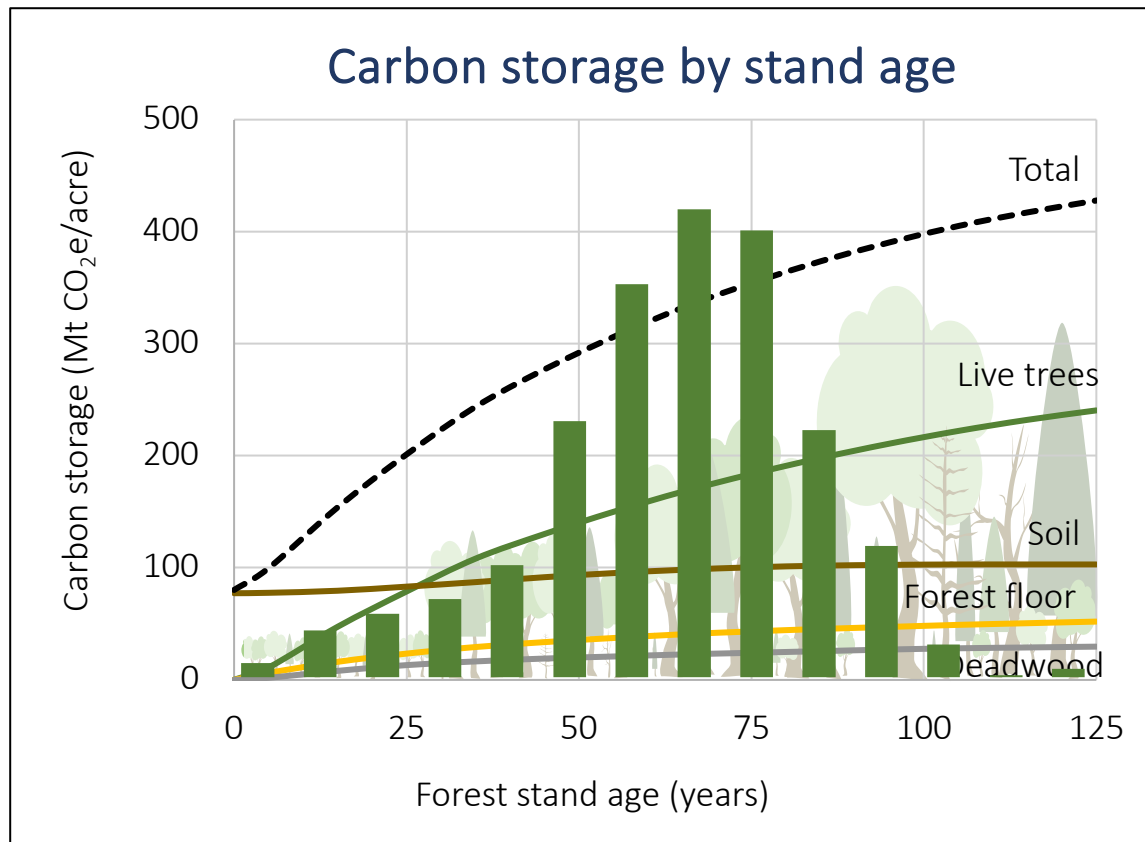


# Carbon storage and sequestration dynamics vary over forest development



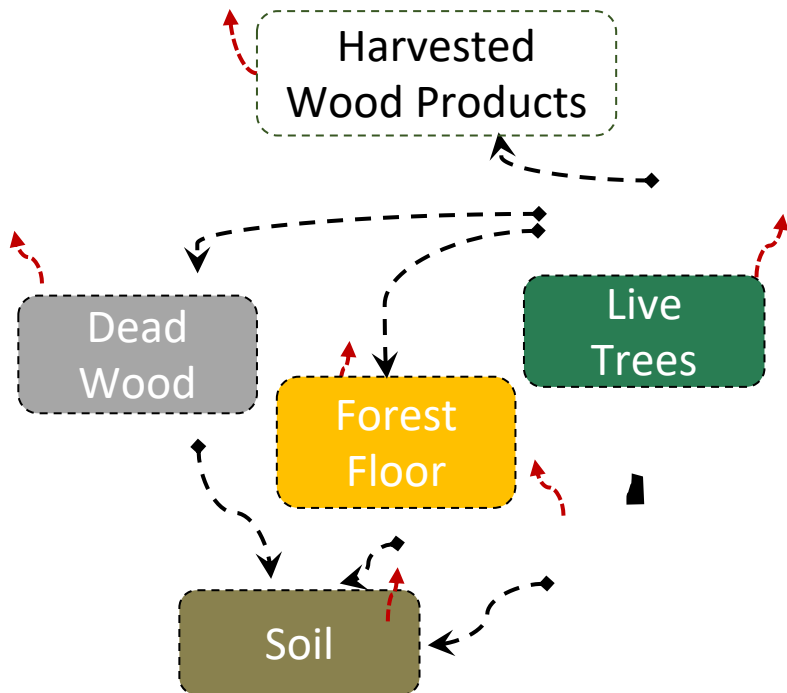
→ Average trends continue based on data from old growth, and old forests

# Carbon storage and sequestration dynamics vary over forest development



# Estimating carbon is challenging and inexact

- What spatial scale is appropriate?
- Over what time scale?
- How do you measure all pools?
- How do you estimate flux?



To estimate carbon flux, need to estimate stock change from inventory data:



Other option: flux tower

Measures flux between forest and the atmosphere

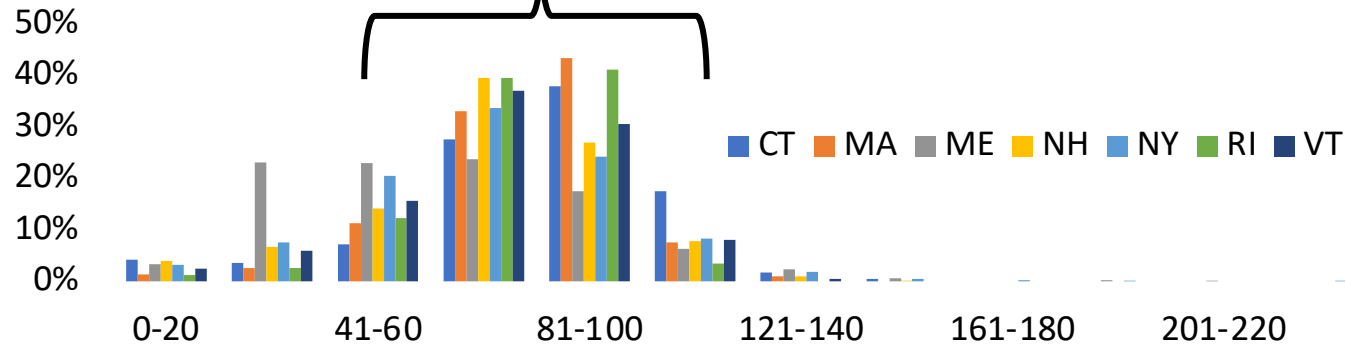
## Forests and their carbon benefits face novel stressors

- Insects and diseases
- Invasive plants
- Earthworms
- Intensive deer browsing
- Climate change

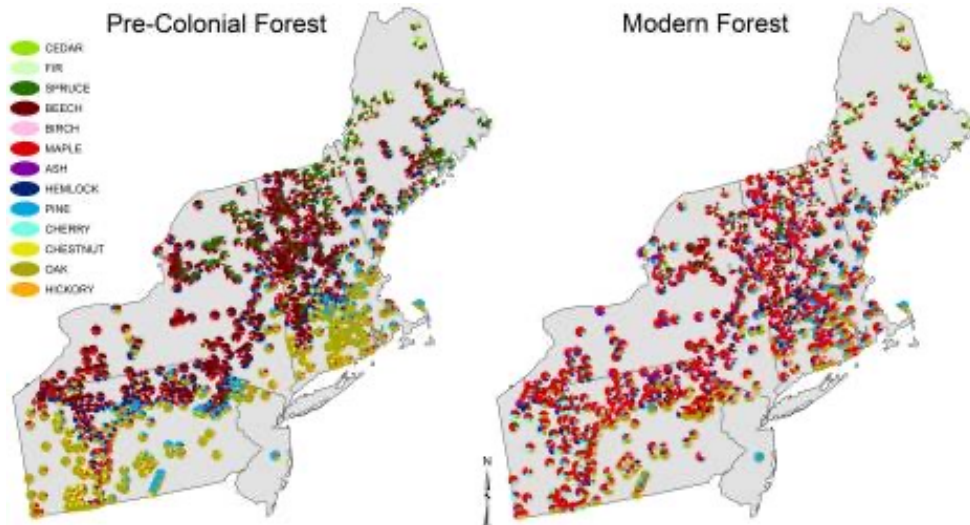


# Land use history altered the species composition, structure, and condition of forests we have today

74% of region's forests between 40-100 years old



Forest structure has been simplified



Species composition has changed



## Use thoughtful forest management to

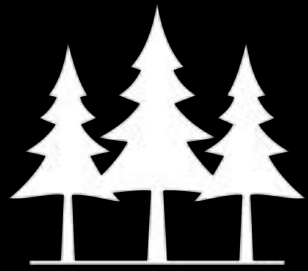
- Create complexity
- Increase species diversity
- Encourage a range of age classes
- Restore ecological functions
- Promote wildlife habitats
- Sustainably harvest resources

→ Promote more resilient forest carbon

Doing so typically requires

1. Harvest to be financially viable
2. Markets for low grade wood

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**The Role of  
Forest Biomass-based Energy  
in Addressing Climate Change**



**Robert Malmshheimer**

Distinguished Teaching Professor of Forest Policy and Law,  
and Associate Chair

Department of Sustainable Resources Management  
SUNY Environmental Science and Forestry

## Some Preliminary Information

**Goal:** Describe the climate change benefits (in the peer-reviewed literature) of using forest biomass energy.

**Important:** My presentation is based on the premise that the forest biomass used to produce energy is sourced from sustainably managed forests and is a byproduct of the harvesting of trees for sawtimber or to meet landowners' management objectives (e.g., timber stand improvement projects, pre-commercial thinnings, providing early successional habitat for birds).

## Intergovernmental Panel on Climate Change

“In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, **while producing an annual sustained yield of *timber, fibre, or energy* from the forest**, will generate the **largest sustained mitigation benefit.**”

Source: Energy Policy and Climate Change IPCC  
(4th Assessment Report)

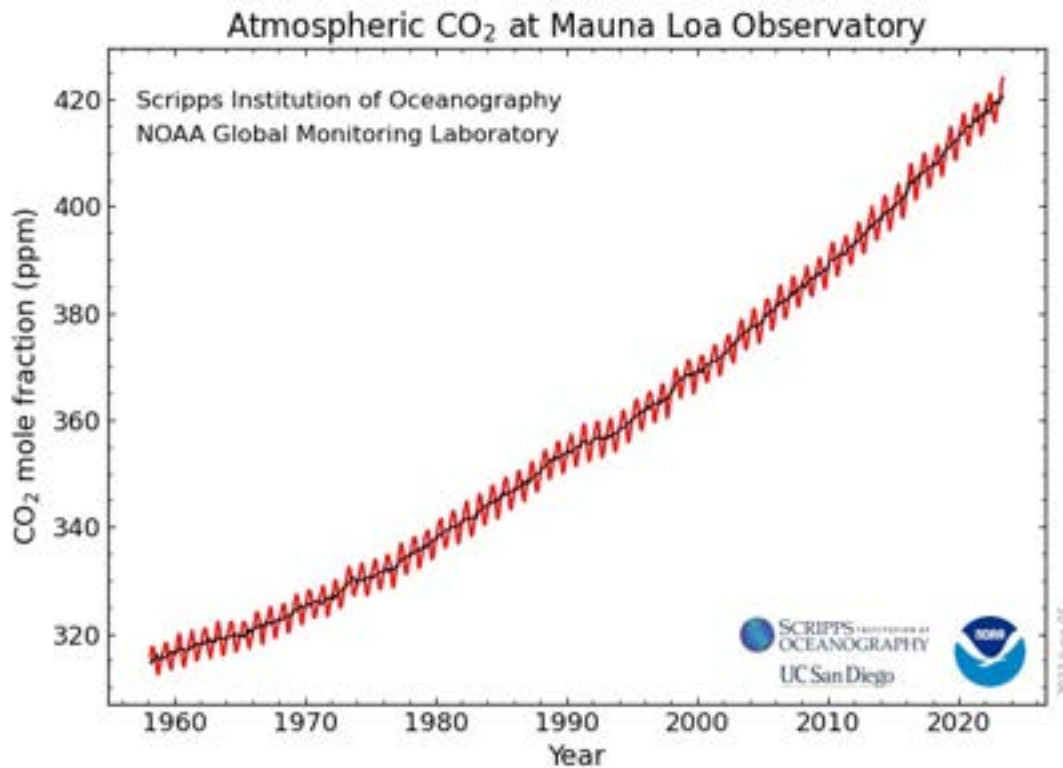
## Presentation Outline

- Understanding Why Climate Change is Occurring
- The Role of Forest Biomass Energy in Addressing Climate Change
- But what about Carbon Debt?
- Another Important Aspect: Markets Matter
- Conclusion

# Understanding Why Climate Change is Occurring

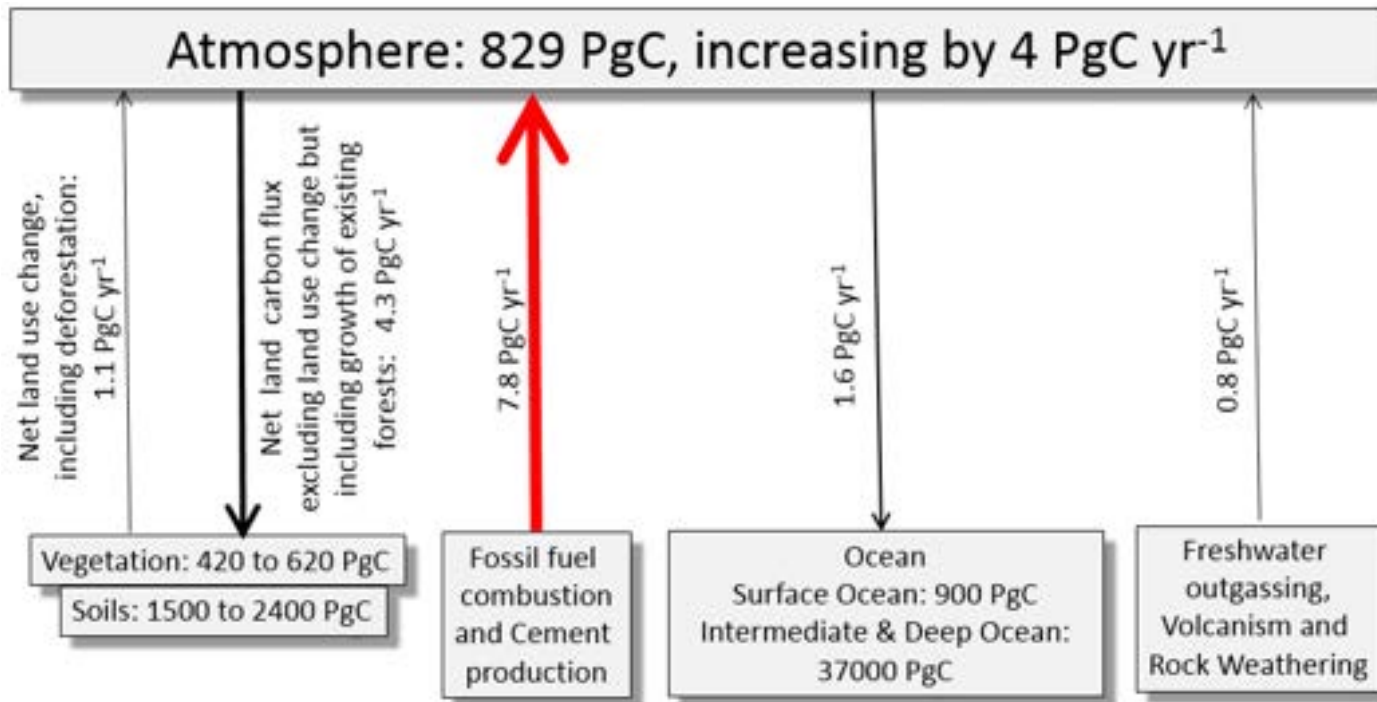


# The Problem: Atmospheric CO<sub>2</sub> Concentrations



Source:  
<https://www.noaa.gov/news-release/broken-record-atmospheric-carbon-dioxide-levels-jump-again>

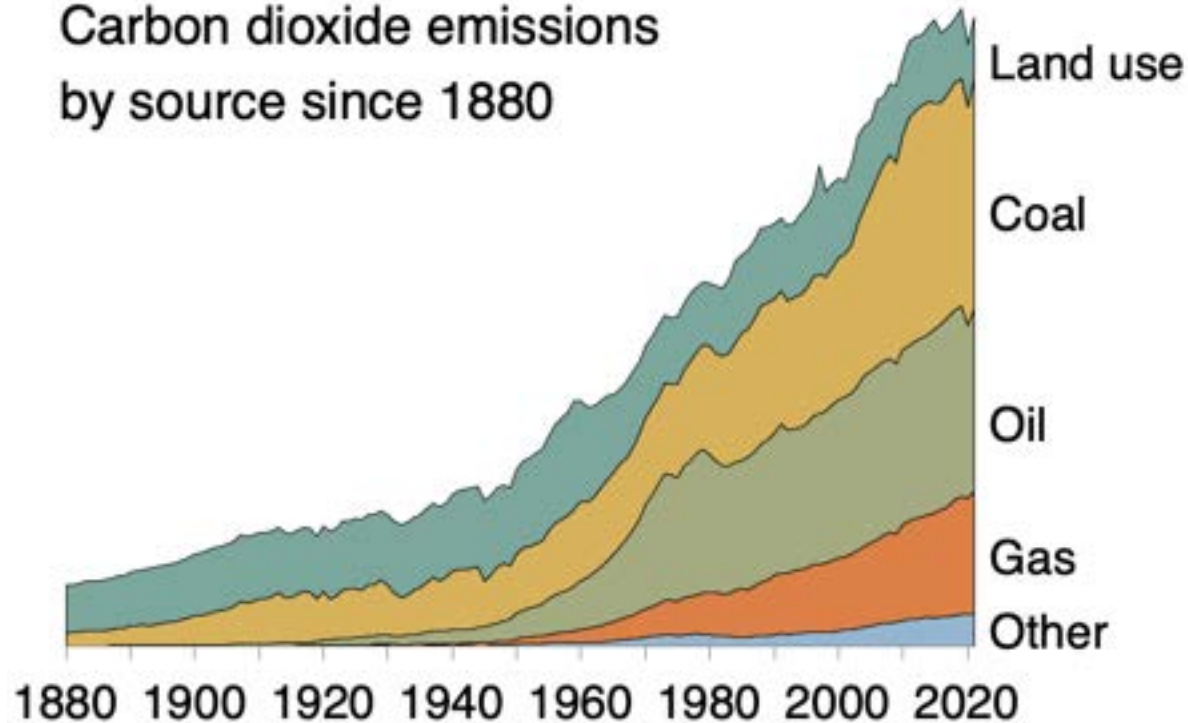
# Fossil Fuel Emissions are the Main Problem



Source: IPCC Fifth Assessment Report, WGI report – Figure 6.1.  
Line widths proportional to amount of flow

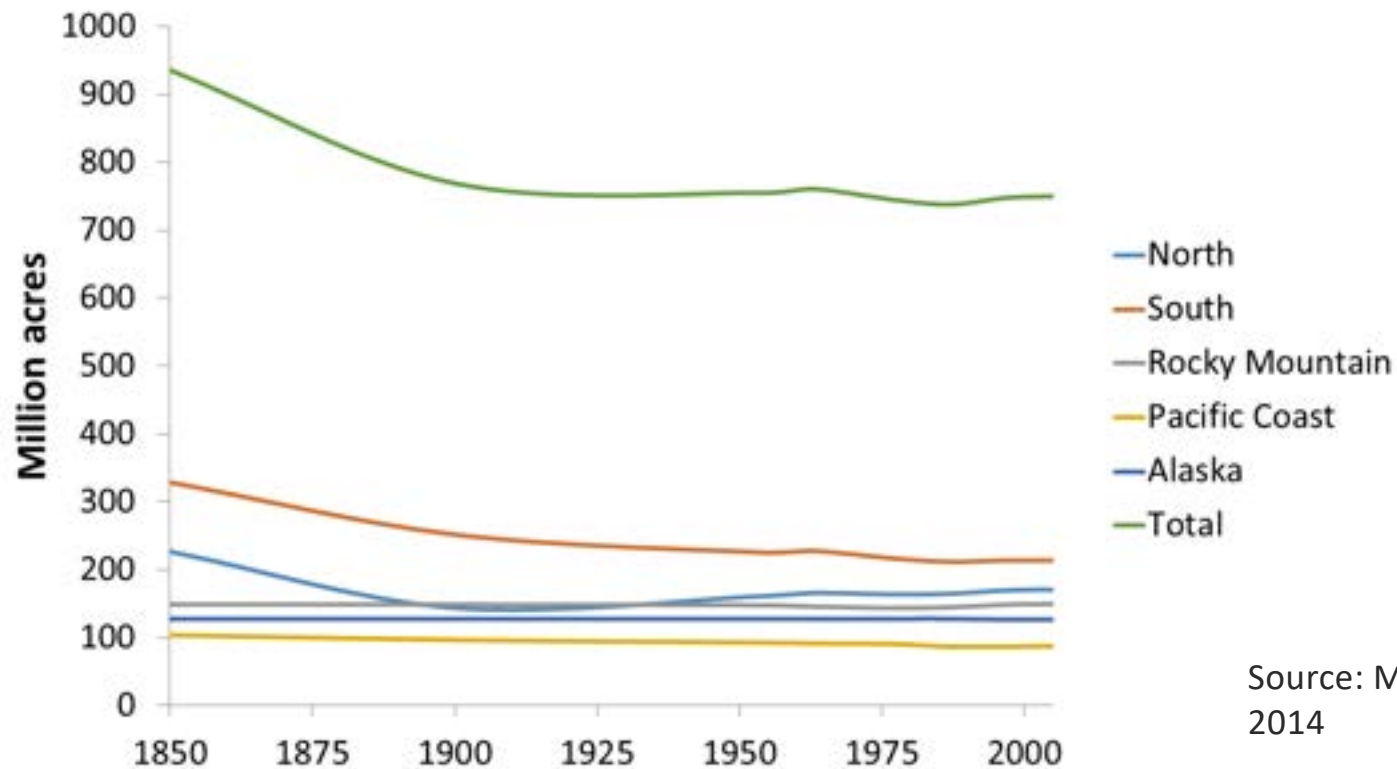
# Fossil Fuel Emissions are the Main Problem

Carbon dioxide emissions by source since 1880



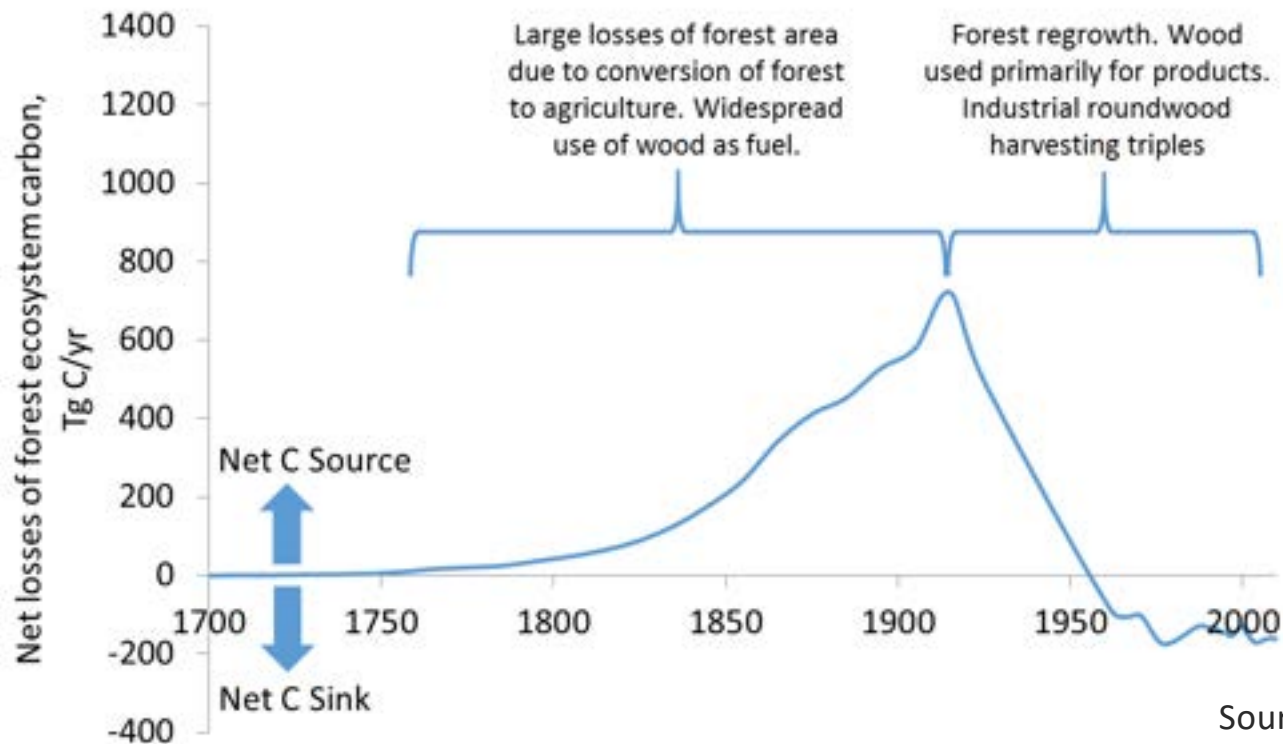
Source:  
[https://pt.m.wikipedia.org/wiki/Ficheiro:CO2\\_Emissions\\_by\\_Source\\_Since\\_1880.svg](https://pt.m.wikipedia.org/wiki/Ficheiro:CO2_Emissions_by_Source_Since_1880.svg)

# US Forest Acreage: Relatively Stable Since 1900



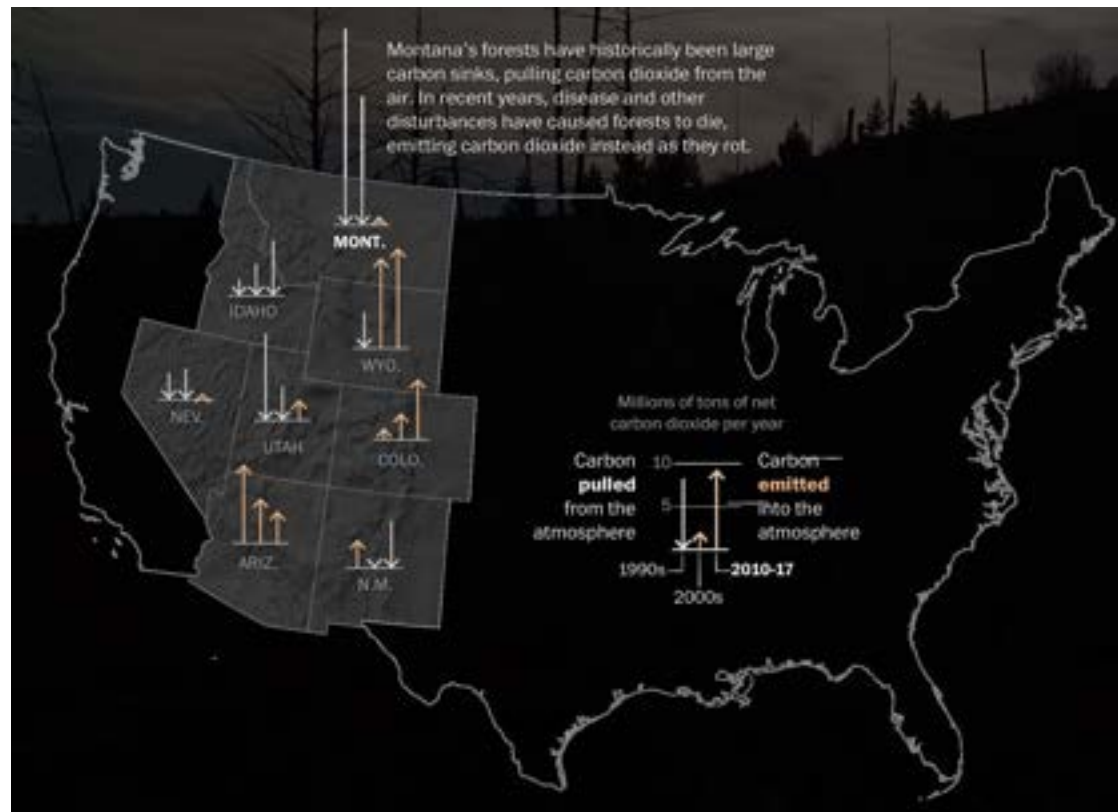
Source: Miner et al. 2014

# US Forests: Carbon Sinks (Not Sources) since 1952



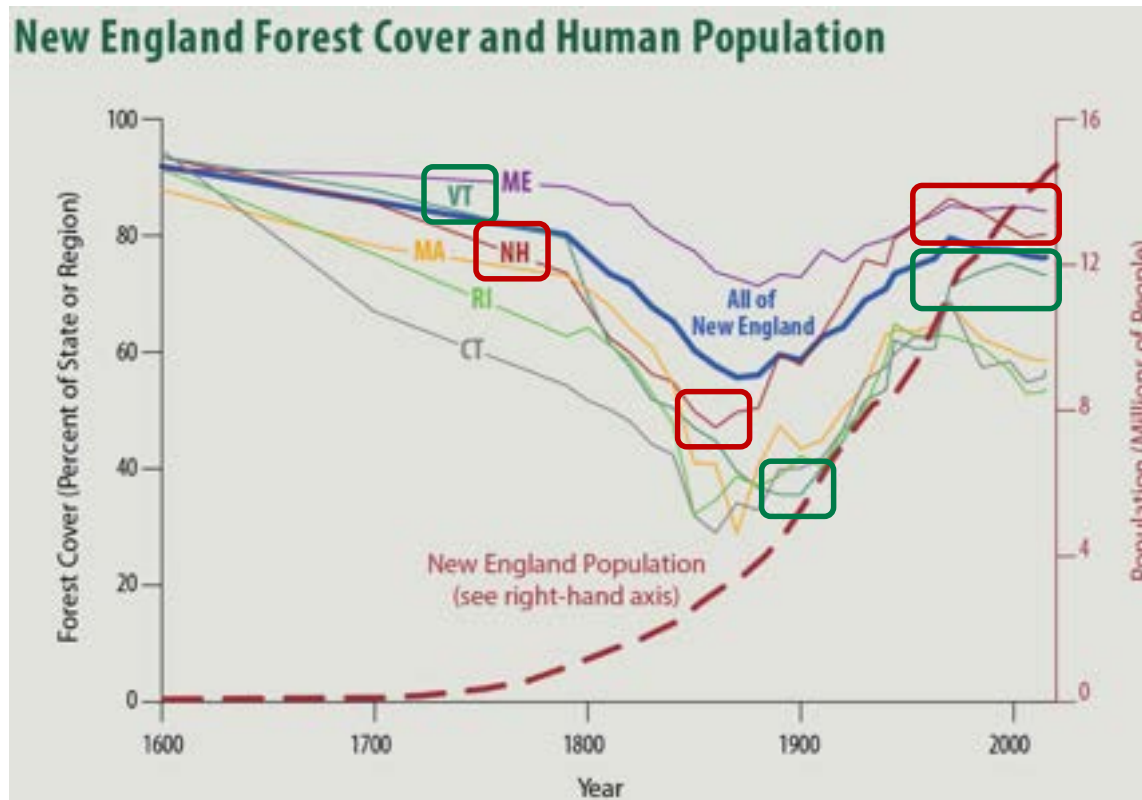
Source: Miner et al. 2014

# US Forests: Carbon Sinks (Not Sources) since 1952



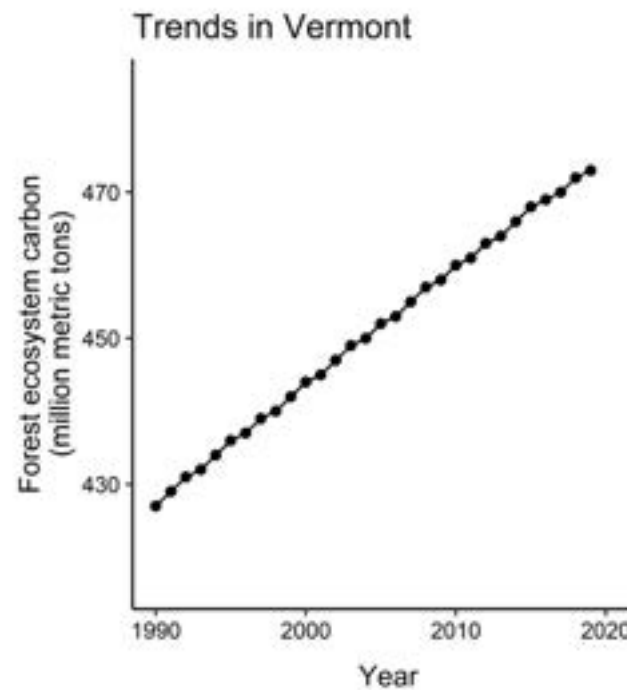
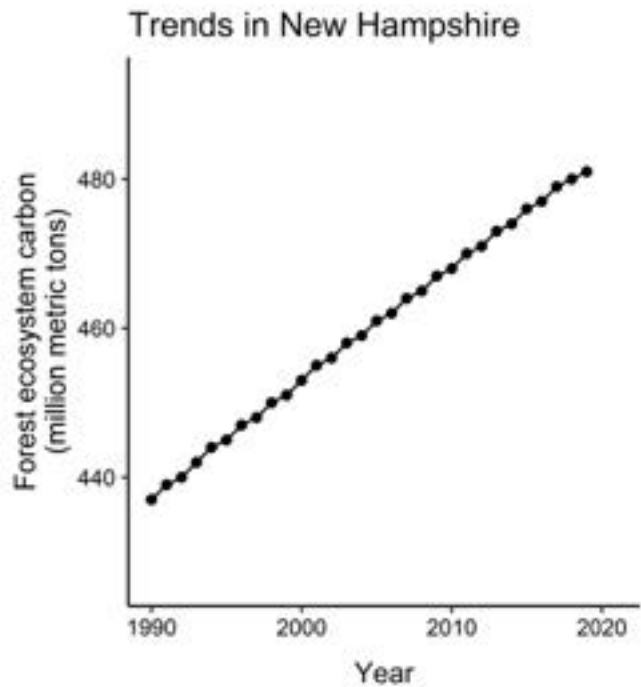
Source:  
<https://www.washingtonpost.com/graphics/2019/national/gone-in-a-generation/forest-climate-change.html>

# NH and VT Forest Acreage: Increasing Since 1900



Source:  
<https://www.vpr.org/post/study-new-england-loses-65-acres-forest-day-development#stream/0>

# NH and VT Forests: Carbon Sinks, Not Sources



Sources:

1. <https://forestresources.org/pdf/Vermont.pdf>
2. <https://forestresources.org/pdf/NewHampshire.pdf>

NOTE: Both sources used "Forest ecosystem carbon stocks obtained from USDA Forest Service Resource Update FS-227: "Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018". State-level CO<sub>2</sub> emissions obtained from EPA State CO<sub>2</sub> Emissions from Fossil Fuel Combustion, 1990-2017. "

# The Role of **Forest Biomass-based Energy** in Addressing Climate Change



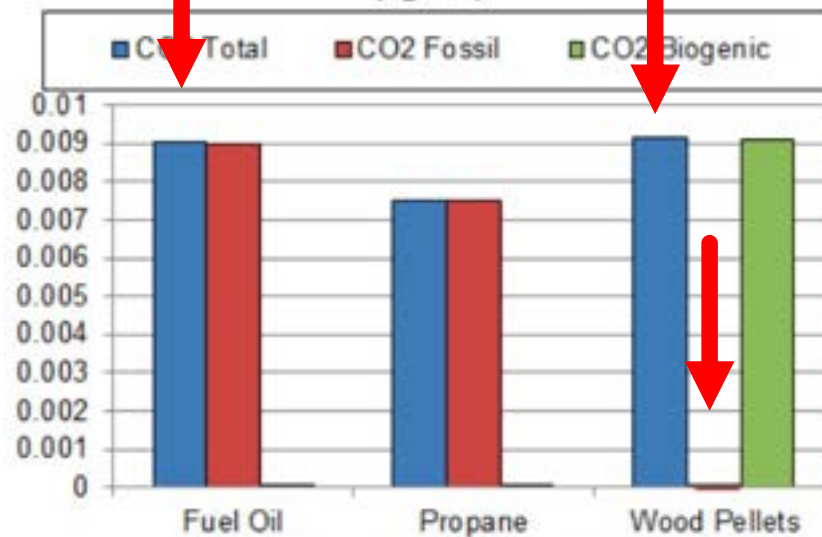
## Bioenergy: The Benefits of Wood-based Energy

As long as wood-producing land remains in forest, whenever we can use wood-based energy, rather than energy made from burning coal, natural gas, or oil, we **reduce fossil fuel-based carbon emissions and get a climate change “Substitution Benefit”.**

# Forest-biomass Energy Emissions and Sustainable Forests

## Wood Boiler Emissions

CO<sub>2</sub> Emissions from Home Heating Using Various Devices (kg/MJ)

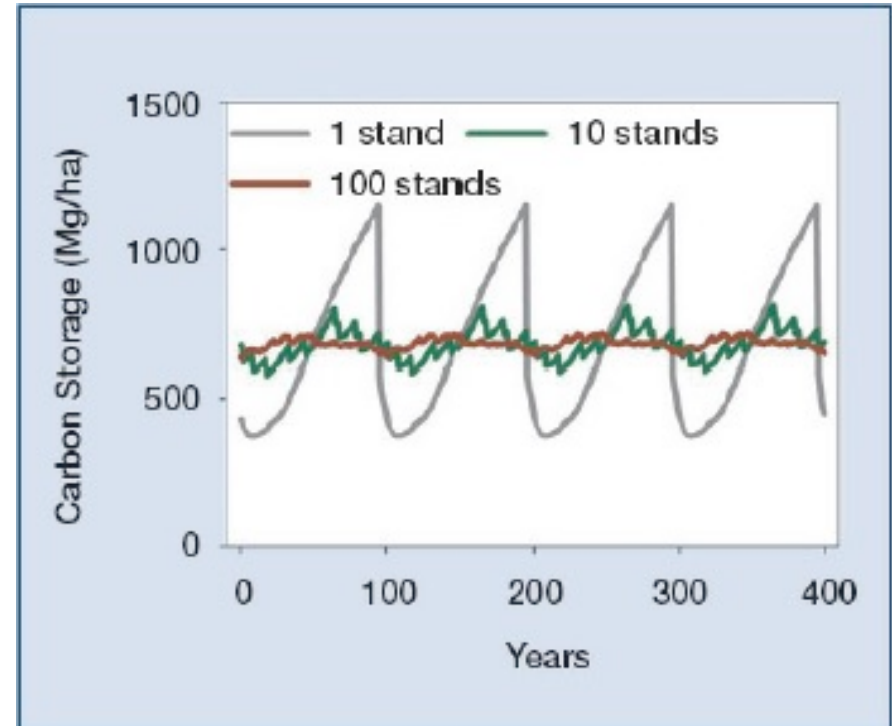
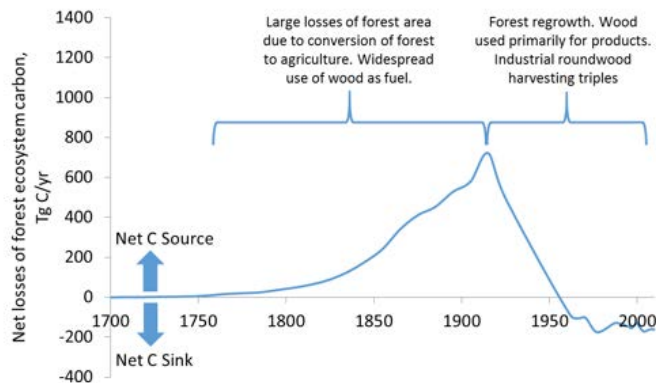


Source: Pa (2010), USEPA (1995).

Source: Bowyer 2012. Life Cycle Impacts of Heating with Wood in Scenarios Ranging from Home and Institutional Heating to Community Scale District Heating Systems

## But What About Carbon Debt?

- The carbon debt debate is about the **timing of climate change benefits** in a **particular forest stand**.



## But What About Carbon Debt?

- The carbon debt debate is about the **timing** of climate change benefits in a **particular forest stand**.
  - The carbon debt concept focuses short-term concerns about biogenic CO<sub>2</sub> emissions.
- However according to the IPCC, it is **cumulative CO<sub>2</sub> emissions** that are correlated with projected peak global temperature.
- Using forest products and bioenergy reduces these cumulative CO<sub>2</sub> emissions. Why?
  - Forest products and bioenergy from sustainably managed lands release mostly biogenic carbon – carbon has already been circulating in the Earth’s carbon cycle -- and therefore this carbon does not increase **cumulative** CO<sub>2</sub> emissions.
    - Note: Forest products and energy do release small amounts of geologic-based carbon emissions (e.g., gasoline in a chain saw, diesel from transportation).
  - Conversely, fossil fuel-based products and energy emit geologic carbon – carbon that increases **cumulative** CO<sub>2</sub> emissions (i.e., the emissions that are causing CO<sub>2</sub> levels in the atmosphere to rise).

# IPCC's Findings on the Warming Effects of Cumulative CO<sub>2</sub> Emissions

- According to the IPCC, cumulative CO<sub>2</sub> emissions are correlated with projected **peak global temperature**.
  - "...taking into account the available information from multiple lines of evidence...,the **near linear relationship between *cumulative CO<sub>2</sub> emissions* and **peak global mean temperature**** is well established..." [emphasis added] (IPCC's Fifth Assessment Report)
- **Caveat:** The IPCC **does** advocate reducing some short term CO<sub>2</sub> emissions.
  - But its **emphasis on reducing short-term CO<sub>2</sub> emissions** is driven primarily by concerns about the "**lock-in**" of **technologies** that increase long-term cumulative CO<sub>2</sub> emissions.
  - Technology Lock-In Example: Investments in new coal or natural gas fuel-based power plants, that because of significant financial investments, will be "locked" into using fossil fuels (and therefore releasing geologic carbon into the atmosphere) for decades.
- **Reminder: Forest products and biomass-based energy reduces cumulative CO<sub>2</sub> emissions – the emissions that matter!**

## Another Important Aspect: Markets Matter



## Increased Demand For Wood Can Provide Forest Carbon Benefits

**Increased demand** for wood triggers investments that (1) **increase forest area**, and (2) **increase forest productivity**.

Multiple sources of evidence in the peer-reviewed literature support this:

- (1) Observations over time,
- (2) empirical studies, and
- (3) modeling.



## Intergovernmental Panel on Climate Change

“In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, **while producing an annual sustained yield of *timber, fibre, or energy* from the forest**, will generate the **largest sustained mitigation benefit.**”

Source: Energy Policy and Climate Change IPCC  
(4th Assessment Report)

# Greenhouse gas emissions of local wood energy from northeastern US forests



Online presentation to the Northern Forest Webinar Series:  
The Carbon Accounting of Modern Wood, January 17 2024

**Dr. Thomas Buchholz (UVM Gund Affiliate)**

**Spatial Informatics Group**

# Overview



- Introduction to Life Cycle Assessments (LCA) for forest products
- LCA results – wood pellets for residential heat in the Northeastern US

# LCA – Definition (ISO 14040)



- International Standard Organization (ISO) 14044: Environmental management — Life cycle assessment — Requirements and guidelines
- Life cycle assessment (LCA) addresses the environmental aspects and potential environmental impacts, (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e., cradle-to-grave).

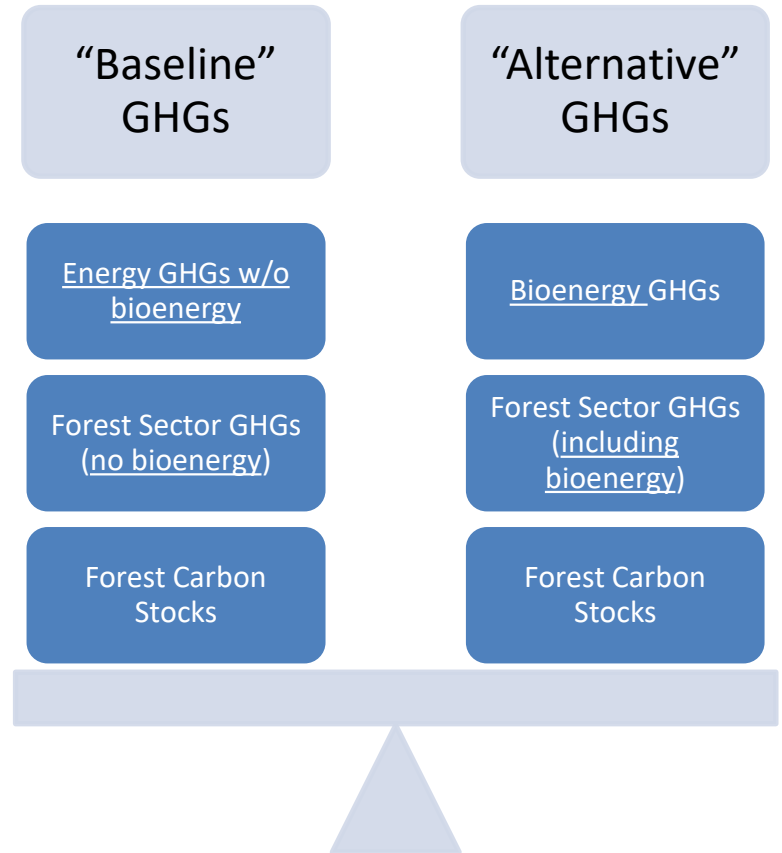
# Comparative Life Cycle Assessment



Source: pixabay.com



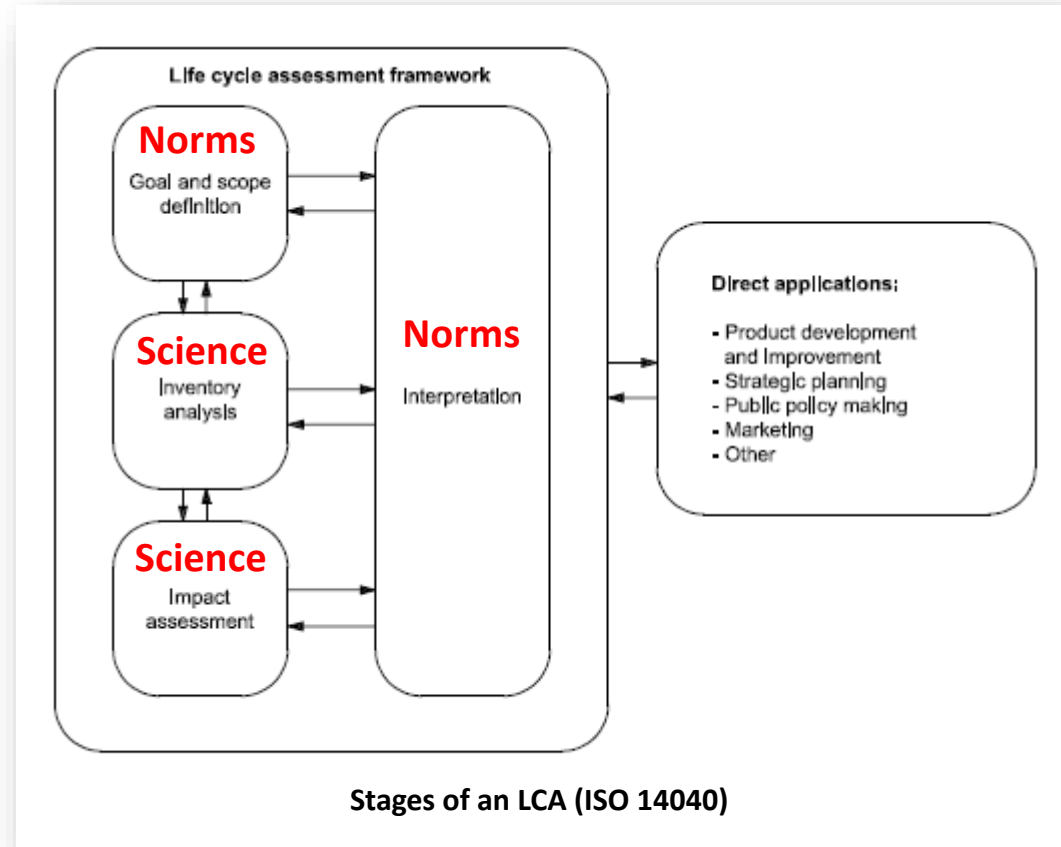
Source: pixabay.com



# LCA Phases (ISO 14040)



- Iterative process for tool development
- Science merged with policy negotiation:
  - Policy norm creation
  - Scientific knowledge production

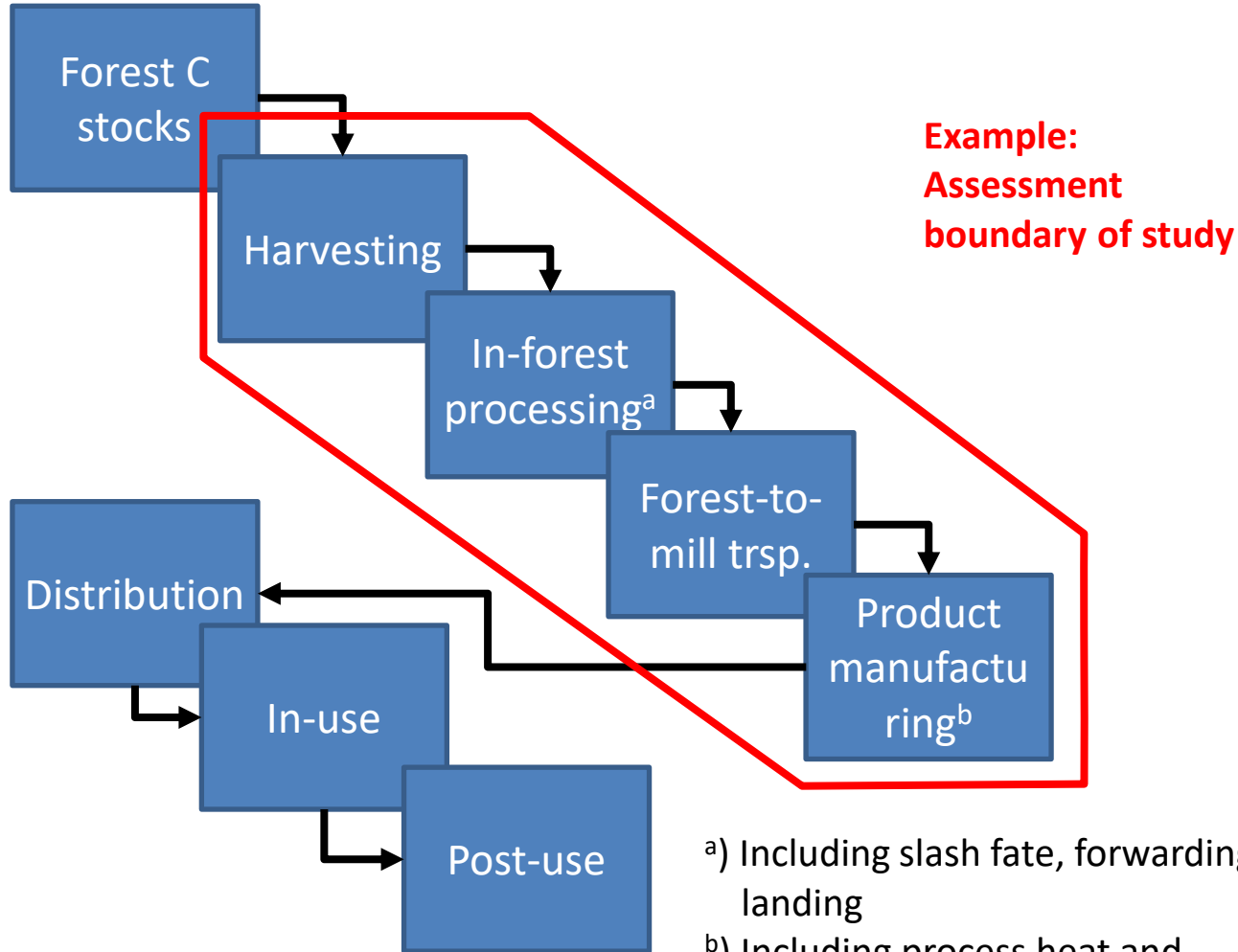


# Life cycle assessment (LCA)



- Comparative LCA:
  - Compare two scenarios on outcomes
  - Use a unifying metric (Metric tonnes of carbon dioxide equivalents – Mg CO<sub>2</sub>e)
- Define scenarios
- Define boundaries:
  - Spatial/accounting elements
  - Temporal: Measure impact over how many years?
- Applied examples:
  - Carbon offset markets (baseline vs. project)
  - Carbon footprint wood-based bioenergy

# LCA example: setting boundaries



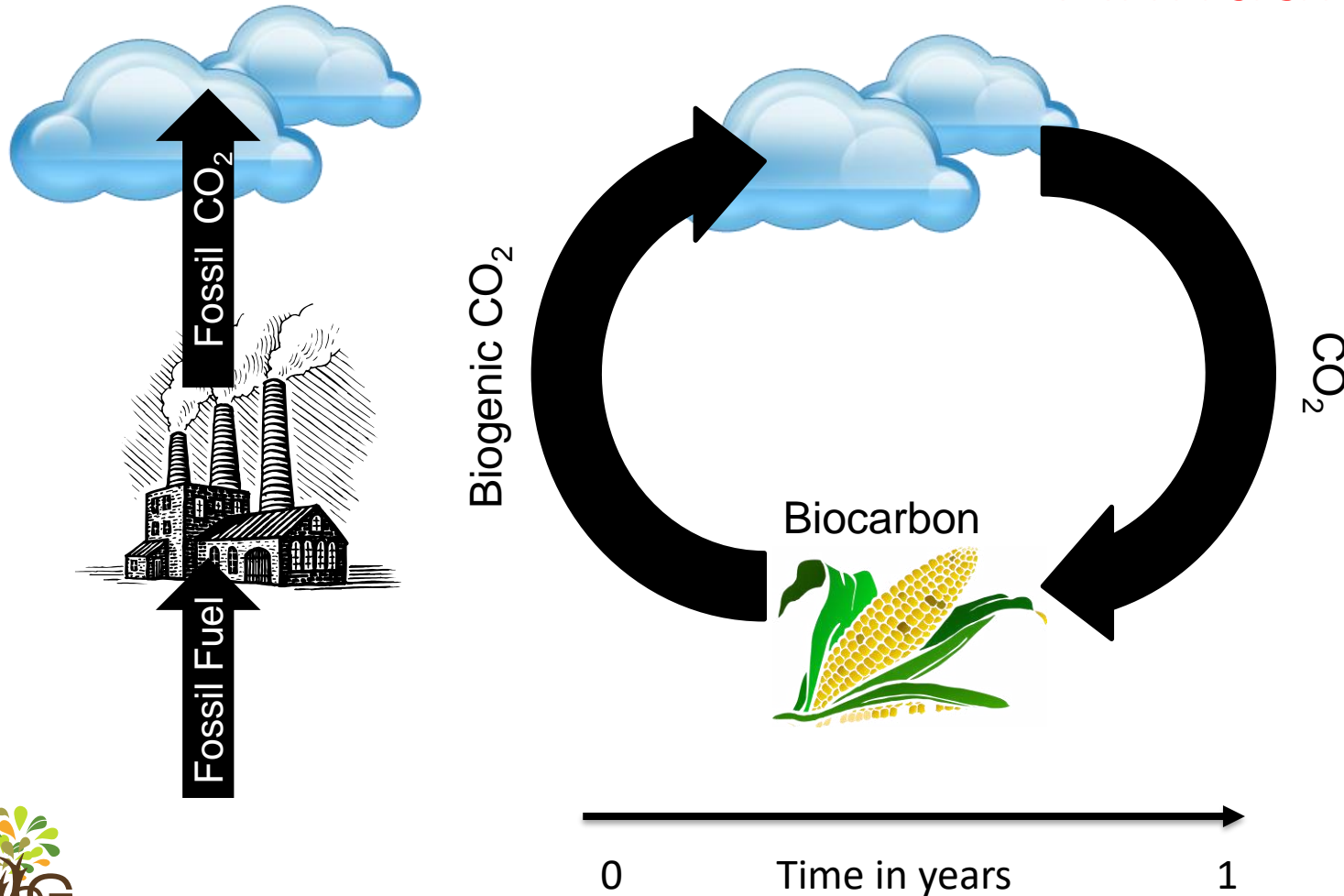
<sup>a)</sup> Including slash fate, forwarding, landing

<sup>b)</sup> Including process heat and electricity production & consumption

# Biocarbon Cycle and Fossil Carbon Emissions



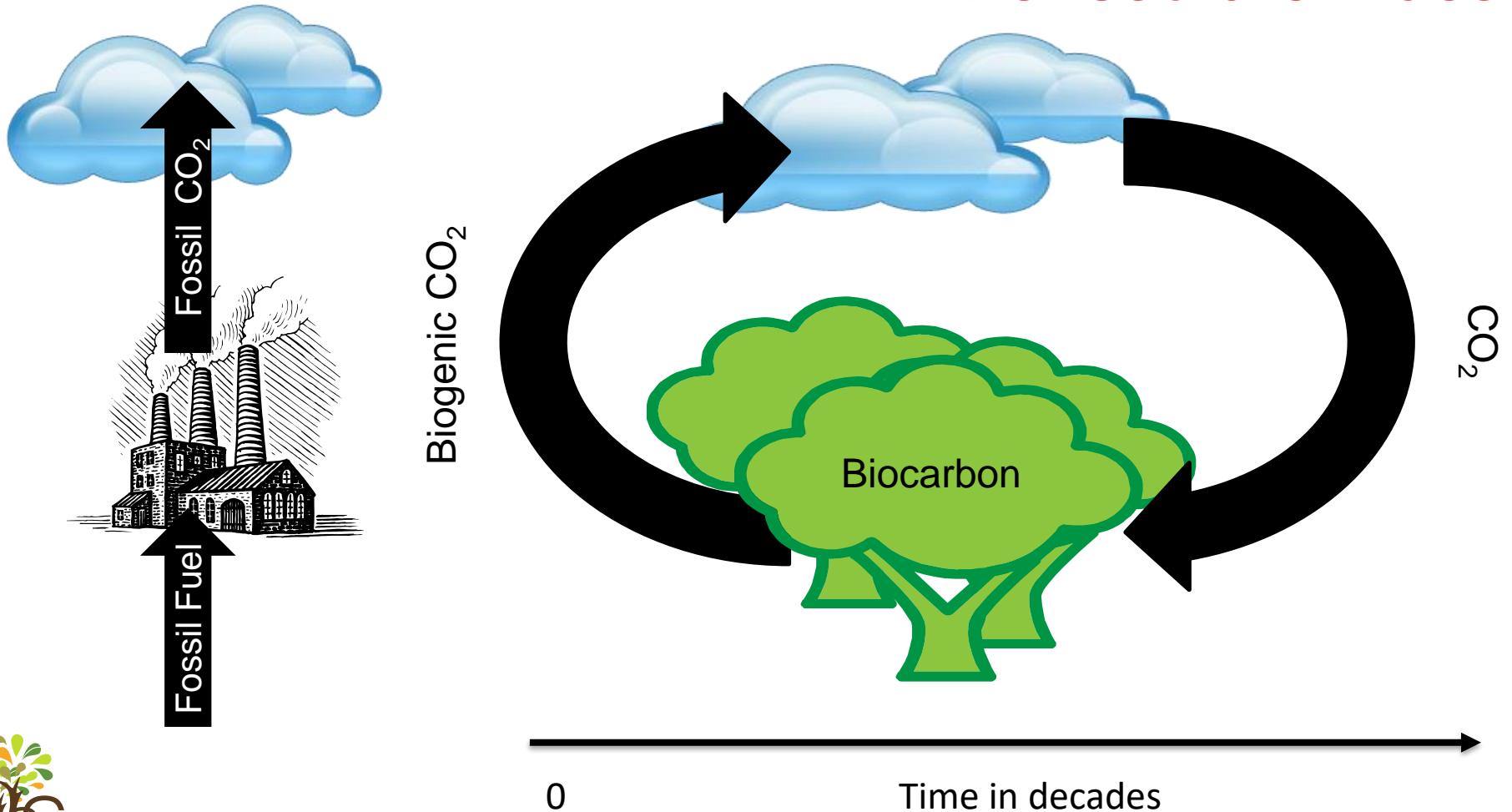
Annual crops



# Biocarbon Cycle and Fossil Carbon Emissions



Forest biomass





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Energy

journal homepage: [www.elsevier.com/locate/energy](http://www.elsevier.com/locate/energy)



## Greenhouse gas emissions of local wood pellet heat from northeastern US forests



Thomas Buchholz <sup>a, b, \*</sup>, John S. Gunn <sup>b, c</sup>, David S. Saah <sup>b, d</sup>

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<sup>b</sup> *Spatial Informatics Group - Natural Assets Laboratory, Pleasanton, CA, USA*

<sup>c</sup> *Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH, USA*

<sup>d</sup> *Department of Environmental Science, University of San Francisco, San Francisco, CA, USA*

# The Key: Baseline assumptions

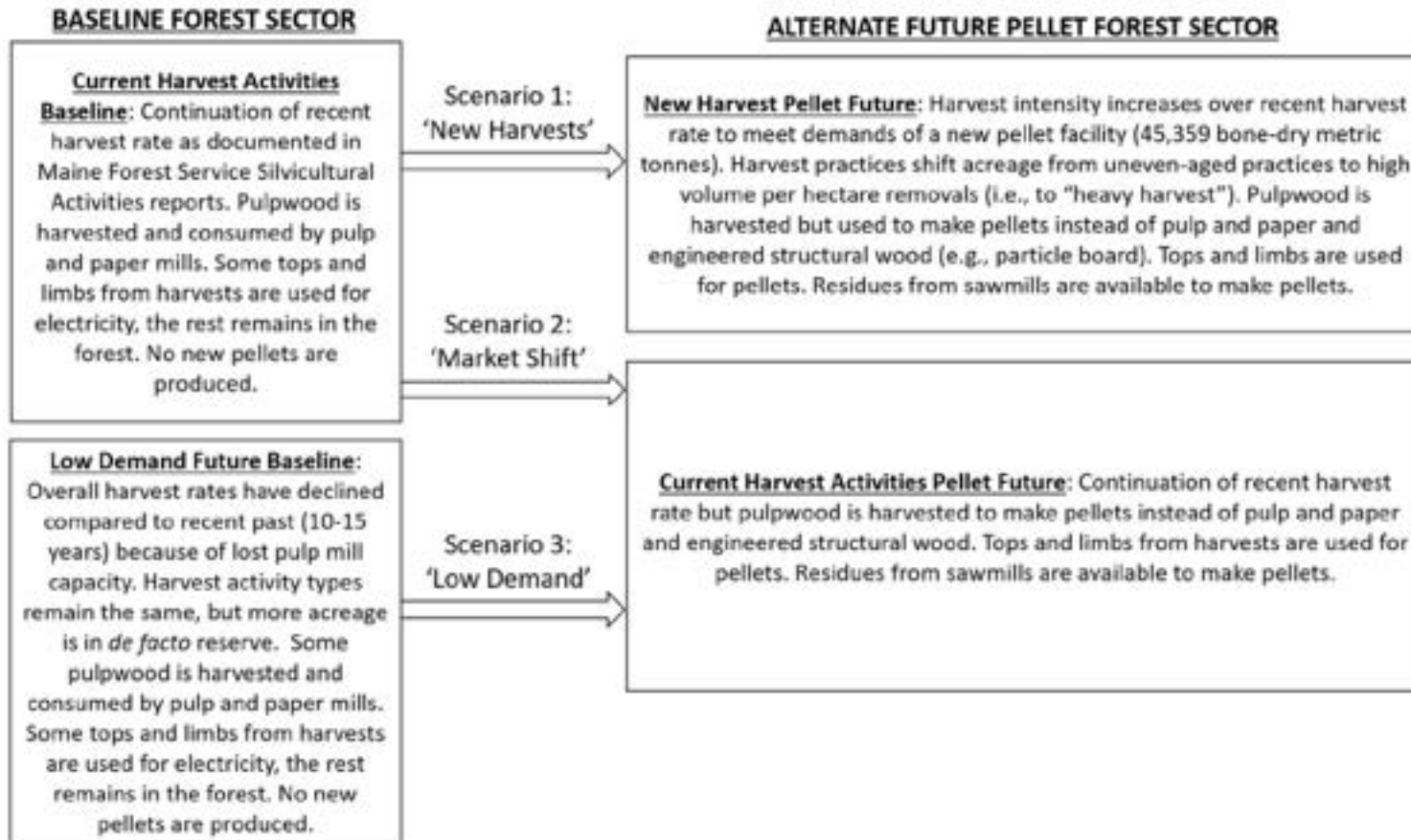
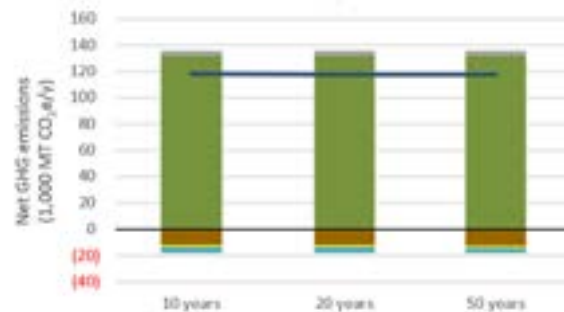


Fig. 1. Forest sector market comparison pathways.

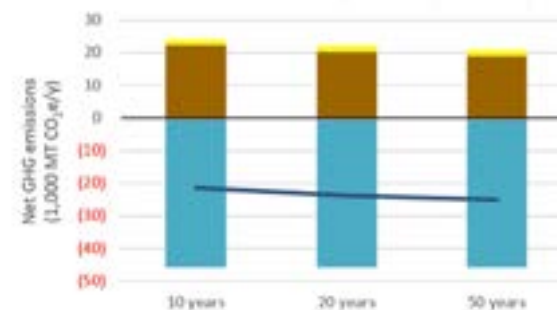
# Forest product carbon pools



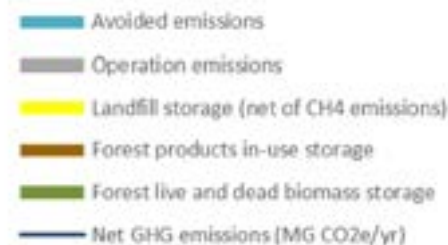
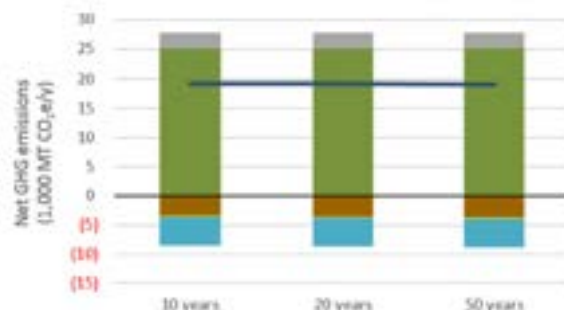
**a) Scenario 1: 'New Harvests';**  
100% pulpwood



**b) Scenario 2 'Market shift';**  
50%/50% pulpwood sawmill residue mix



**c) Scenario 3: 'Low demand';**  
100% pulpwood



**Fig. 2.** Net GHG emissions across a representative wood supply area in the northeastern US by carbon accounting category and timescale with example feedstock mixes for each economic scenario. All scenarios assume that 50% of the feedstock is derived from sawmill residues while the remaining 50% are sourced from forest operations. Pellets from new harvests in addition to current harvest activities (Figure 2a) as well as pellets derived from harvests that would have not been executed due to the closing of pulp mills (Figure 2c) result in a net GHG increase mostly driven by net GHG emissions occurring in forest carbon pools (green). Pellets derived from harvests that would have occurred anyway to supply (now closed) pulp mills (Figure 2b) result in a net GHG decrease mostly driven by reduced avoided fossil fuel emissions from both pulp manufacturing and fossil-fuel based heat. See Fig. 1 for an explanation on the three forest sector market scenarios. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

# Sourcing of biomass



**Table 3**  
GHG emissions by economic scenario and timescale when displacing home heating oil with regionally sourced wood pellets in the Northern Forest. Net GHG emissions (MT CO<sub>2</sub>e/y) are across the wood supply area and inclusive of upstream and downstream forest sector emissions. Green and red shading indicate positive and negative climate benefits, respectively. Plant size was scaled for 45,359 MT of annual pellet production and partly limited by scenario-specific wood supply area forest growth limits.

Scenario Title	Feedstock			Pellet Net GHG emissions									Results Category
	0%	Source	100%	MT CO <sub>2</sub> e/Y			% Change			MT CO <sub>2</sub> e/MT Pellets			
	Pulpwood	Sawmill Residues		10 y	20 y	50 y	10 y	20 y	50 y	10 y	20 y	50 y	
1 'New harvests'				27,240	29,886	31,474	3%	4%	4%	0.6	0.7	0.7	Climate Neutral
1 'New harvests'				57,361	59,030	60,032	7%	8%	8%	1.3	1.4	1.4	Climate Negative
1 'New harvests'				87,553	88,245	88,660	11%	11%	12%	2.1	2.1	2.1	Climate Negative
1 'New harvests'				117,813	117,527	117,356	15%	15%	15%	2.8	2.8	2.8	Climate Negative
2 'Market shift'	Harvest Residues			20,665	2,231	-21,292	2%	0%	-3%	0.5	0.0	-0.5	Climate Neutral
2 'Market shift'				-85,185	-85,185	-85,185	-11%	-11%	-11%	-1.9	-1.9	-1.9	Climate Beneficial
2 'Market shift'				-53,411	-54,452	-55,077	-7%	-7%	-7%	-1.2	-1.2	-1.2	Climate Beneficial
2 'Market shift'				-21,558	-23,640	-24,889	-3%	-3%	-3%	-0.5	-0.5	-0.5	Climate Neutral
2 'Market shift'				10,376	7,253	5,379	1%	1%	1%	0.2	0.2	0.1	Climate Neutral
2 'Market shift'				42,388	38,224	35,725	5%	5%	5%	0.9	0.8	0.8	Climate Negative
3 'Low demand'				-76,441	-73,437	-71,635	-10%	-9%	-9%	-1.7	-1.6	-1.6	Climate Beneficial
3 'Low demand'				-44,604	-42,641	-41,463	-6%	-5%	-5%	-1.0	-0.9	-0.9	Climate Beneficial
3 'Low demand'				-12,674	-11,752	-11,199	-2%	-2%	-1%	-0.3	-0.3	-0.2	Climate Neutral
3 'Low demand'				19,343	19,224	19,153	2%	2%	3%	0.4	0.4	0.4	Climate Neutral

# GHG impact: Residential heating

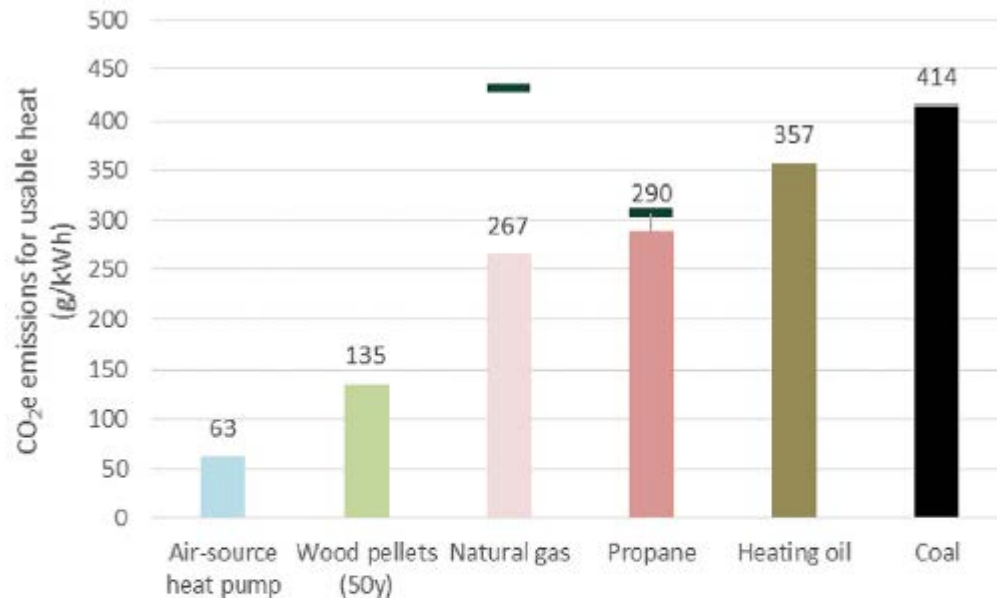


Fig. 3. Net GHG emissions for residential heat from heat of pellets vs. other heating alternatives in the Northern Forest for pellet Scenario 2 'Market Shift' and a feedstock mix of 50% sawmill residue, 50% pulpwood. While this metric suggests a strong impact of heating alternative, wood supply area analysis suggests only a muted impact of heating alternative on GHG emissions. Black bars for natural gas and propane present potential net GHG emissions for these fuels when including methane distribution losses of 2.4% natural gas [28] and 0.24% for propane.

# Outlook



- Baseline and future scenario assumptions drive results
  - Volume of biomass (does current market support demand?)
  - Supply/Demand study to determine ‘risk’ for additional harvests
- ‘Let Grow’/‘no forest management’ scenario is becoming more and more part of the political debate
- Biomass markets in the NE rarely drive harvest decisions but can intensify harvests (Buchholz et al. 2019)
- Nothing beats a ‘let grow’ scenario in terms of forest carbon stock accumulation in the short to middle term – **in the absence of stochastic events** (beetle, drought, storm, fire, etc.)
- Forest C stock trajectories are uncertain, some harvest activities can stabilize carbon (e.g., beetle risk; Gunn et al. 2020)



# Questions?

**For Questions:**

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# LCA – Phases (ISO 14040)



## Four phases in an LCA study:

### a) Goal and scope definition phase,

- The **scope**, including **system boundary** and **level of detail**, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.

### b) Inventory analysis phase (LCI),

- Inventory of input/output **data** with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.

### c) Impact assessment phase (LCIA),

- Provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

### d) Interpretation phase.

- Results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

# Selected key LCA features (ISO 14040)



- ***“There is no single method for conducting LCA. Organizations have the flexibility to implement LCA as established in this International Standard, in accordance with the intended application and the requirements of the organization;”***
- ***“LCA addresses potential environmental impacts; **LCA does not predict absolute or precise environmental impacts** due to:***
  - *the relative expression of potential environmental impacts to a reference unit,*
  - *the integration of environmental data over **space and time**,*
  - *the **inherent uncertainty in modelling** of environmental impacts, and*
  - *the fact that some possible environmental impacts are clearly **future impacts**;*”