Carbon & Climate-Smart Forestry: Forest protection and management options for climate mitigation

Sara Kuebbing
Director of Research
Yale Applied Science Synthesis Program

Disclaimer: Carbon should probably not be the *primary* reason to manage forests.








Photos by Katy Wilkens, Mike Arney, Erik Karits, Sebastian Pichler, Karsten Winegart, Alex Reynolds on Unsplash.

Carbon & Climate-Smart Forestry: Forest protection and management options for climate mitigation

Sara Kuebbing
Director of Research
Yale Applied Science Synthesis Program

Overview

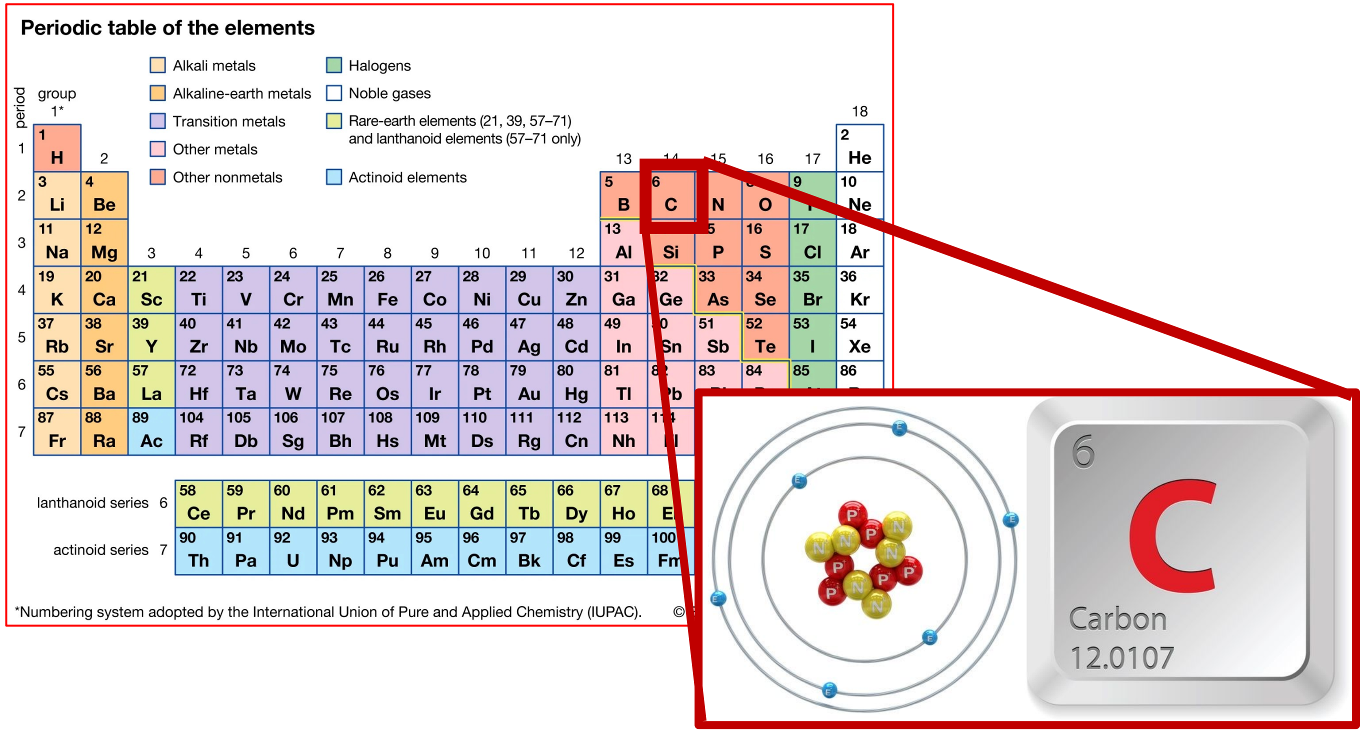
1) Why "**carbon forestry**" is the new hot topic in **climate** mitigation

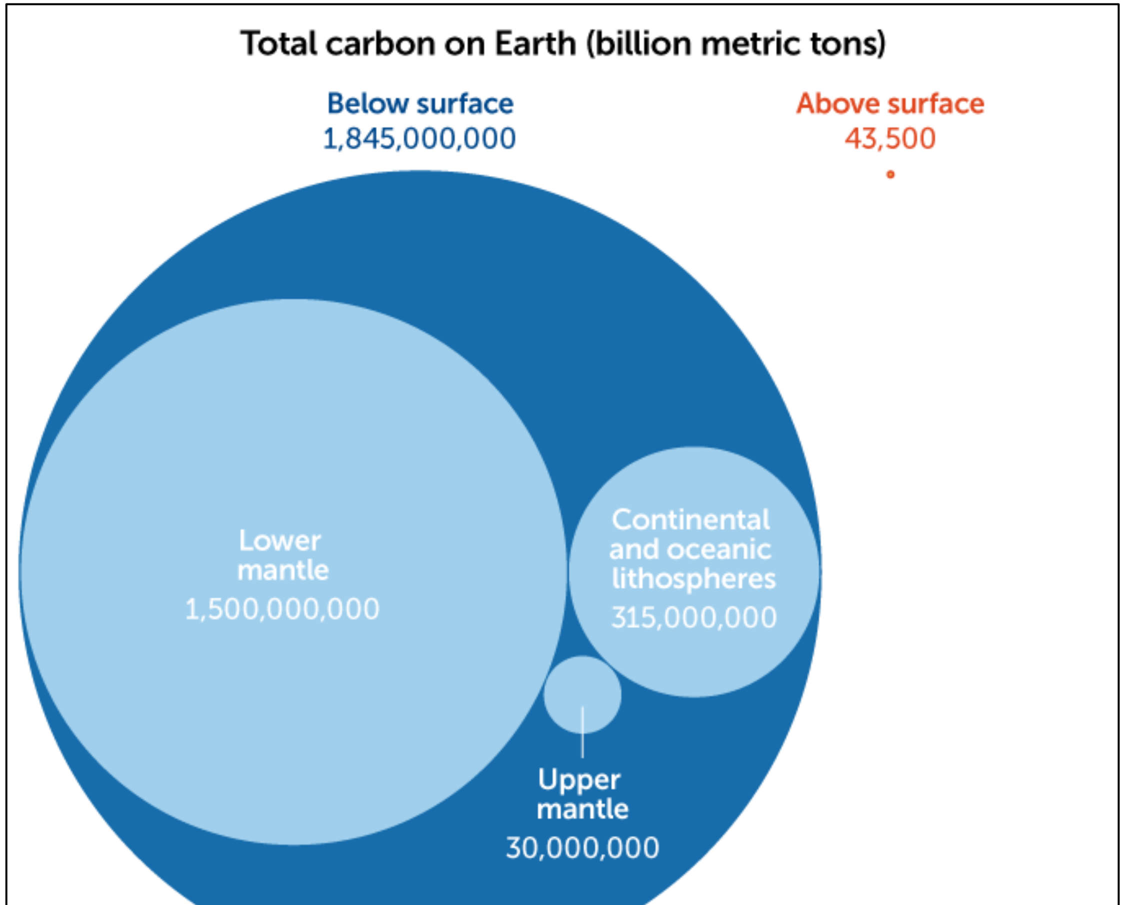
2) Why **carbon**, **forestry**, and **climate** are deeply entwined
[or, an Overview of Forest Carbon Cycling]

3) **Carbon** & **Climate**-Smart **Forestry**: some numbers

Why “carbon forestry” is the new hot topic

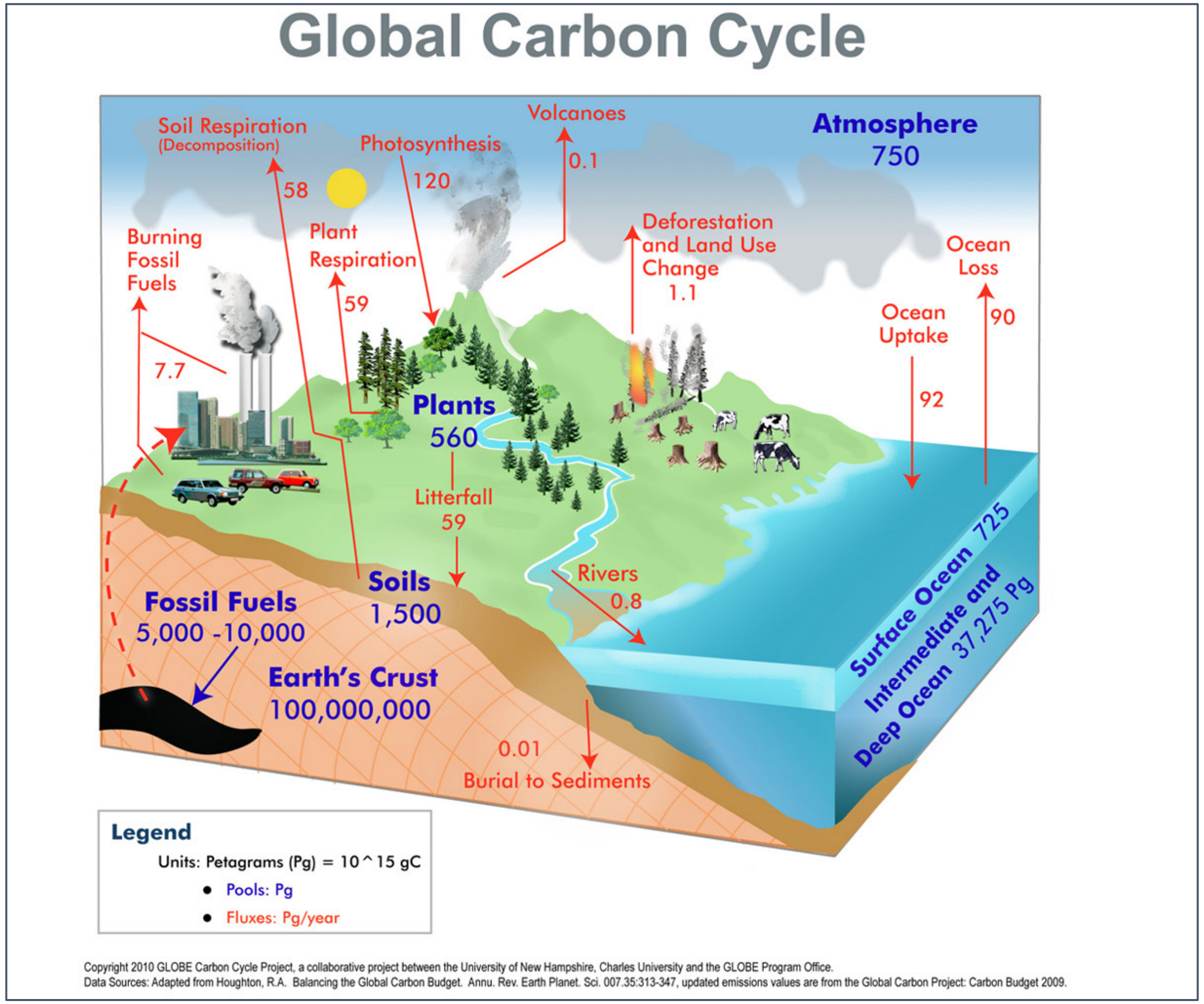
We have 1.8 billion billion metric tons of Carbon on Earth



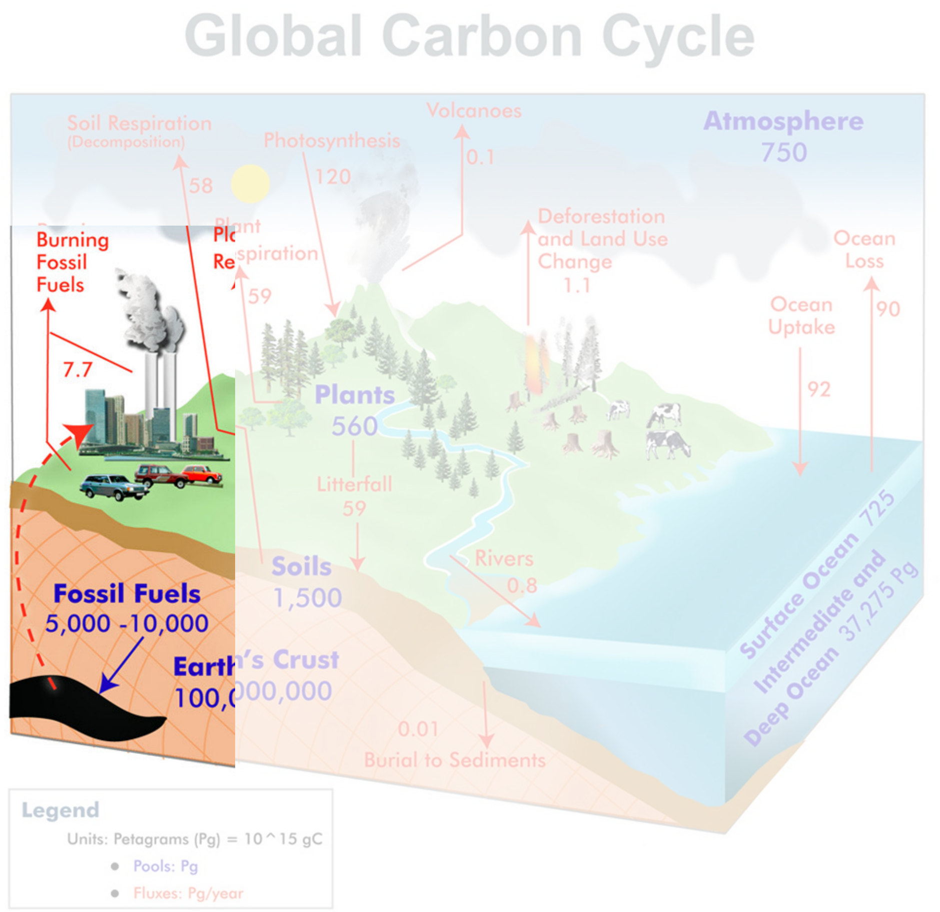


Source: C.A. Suarez, M. Edmonds and A.P. Jones/Elements 2019

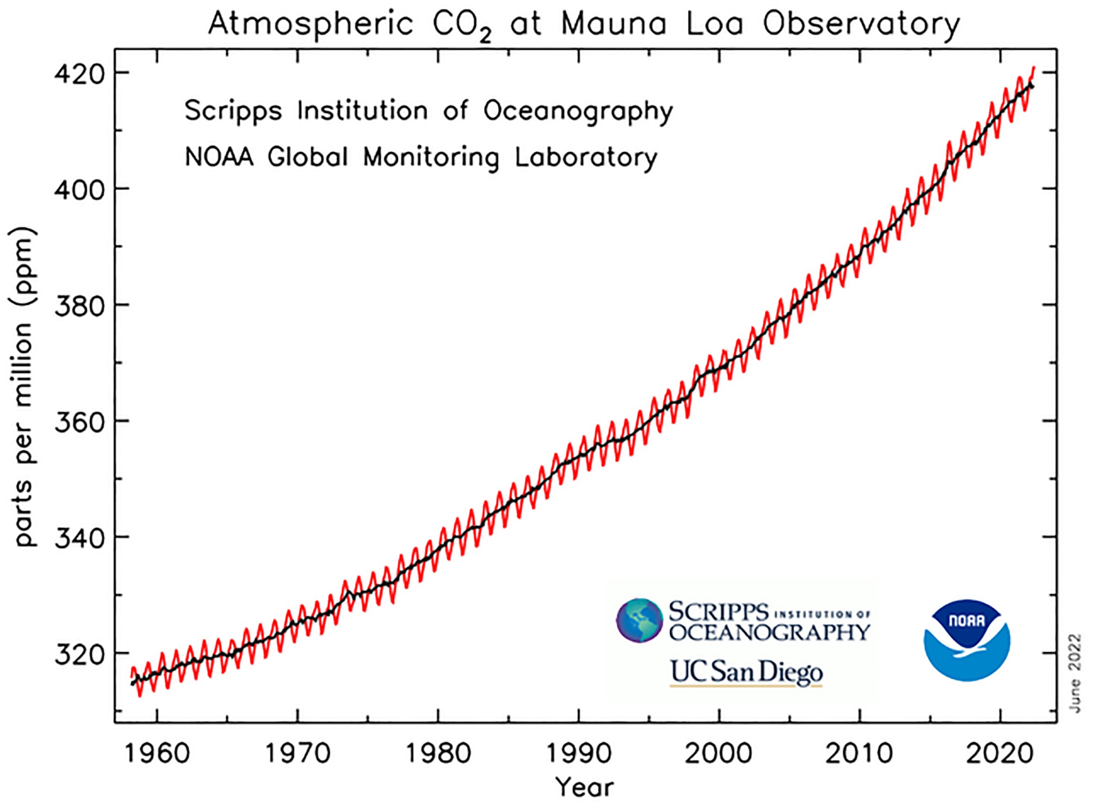
Carbon flows between the atmosphere, ecosystems, and the earth's crust..



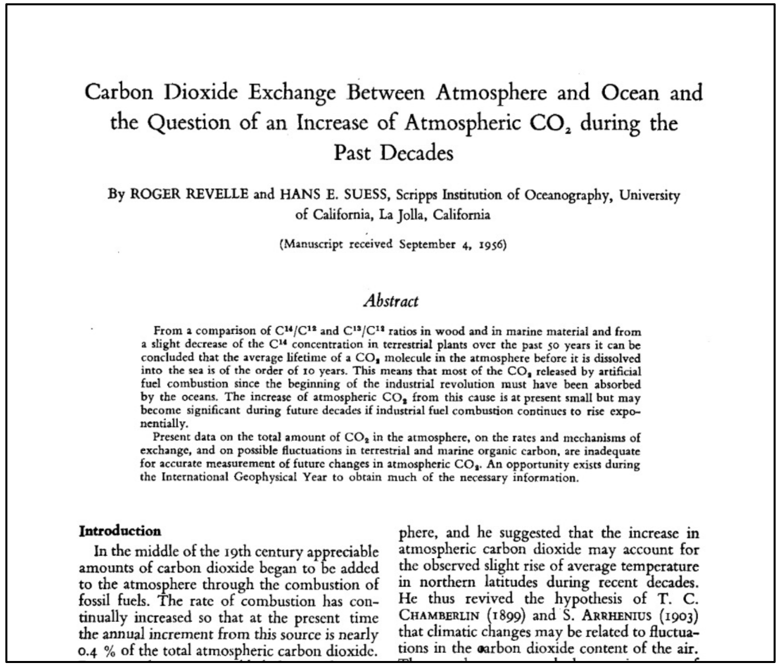
Humans have increased the total amount of atmospheric carbon by burning fossil fuels



Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.



1950's: first scientific evidence of irreversible atmospheric change



Carbon Dioxide Exchange Between Atmosphere and Ocean and the Question of an Increase of Atmospheric CO_2 during the Past Decades

By ROGER REVELLE and HANS E. SUESS, Scripps Institution of Oceanography, University of California, La Jolla, California

(Manuscript received September 4, 1956)

Abstract

From a comparison of C^{14}/C^{12} and C^{13}/C^{12} ratios in wood and in marine material and from a slight decrease of the C^{14} concentration in terrestrial plants over the past 50 years it can be concluded that the average lifetime of a CO_2 molecule in the atmosphere before it is dissolved into the sea is of the order of 10 years. This means that most of the CO_2 released by artificial fuel combustion since the beginning of the industrial revolution must have been absorbed by the oceans. The increase of atmospheric CO_2 from this cause is at present small but may become significant during future decades if industrial fuel combustion continues to rise exponentially.

Present data on the total amount of CO_2 in the atmosphere, on the rates and mechanisms of exchange, and on possible fluctuations in terrestrial and marine organic carbon, are inadequate for accurate measurement of future changes in atmospheric CO_2. An opportunity exists during the International Geophysical Year to obtain much of the necessary information.

Introduction

In the middle of the 19th century appreciable amounts of carbon dioxide began to be added to the atmosphere through the combustion of fossil fuels. The rate of combustion has continually increased so that at the present time the annual increment from this source is nearly 0.4 % of the total atmospheric carbon dioxide.

phere, and he suggested that the increase in atmospheric carbon dioxide may account for the observed slight rise of average temperature in northern latitudes during recent decades. He thus revived the hypothesis of T. C. CHAMBERLIN (1899) and S. ARRHENIUS (1903) that climatic changes may be related to fluctuations in the carbon dioxide content of the air.

1980's: Vocal, global concern about fossil fuel emissions

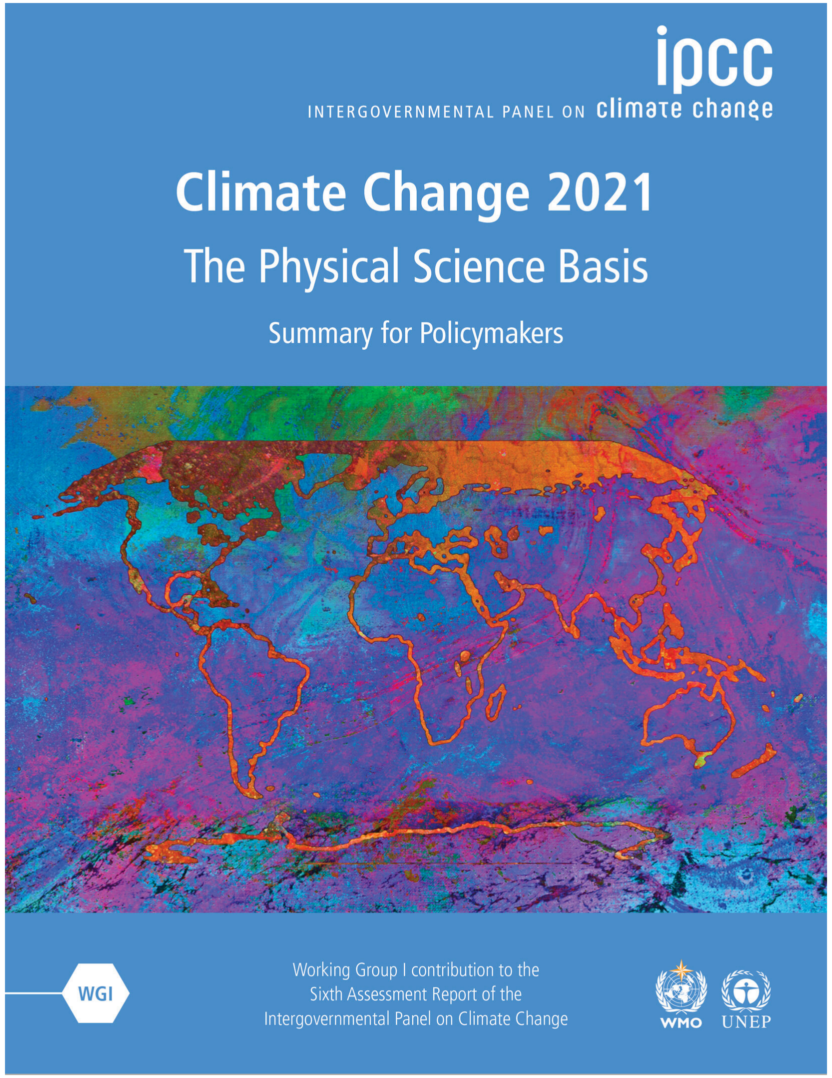
@CharlVera, Pixabay

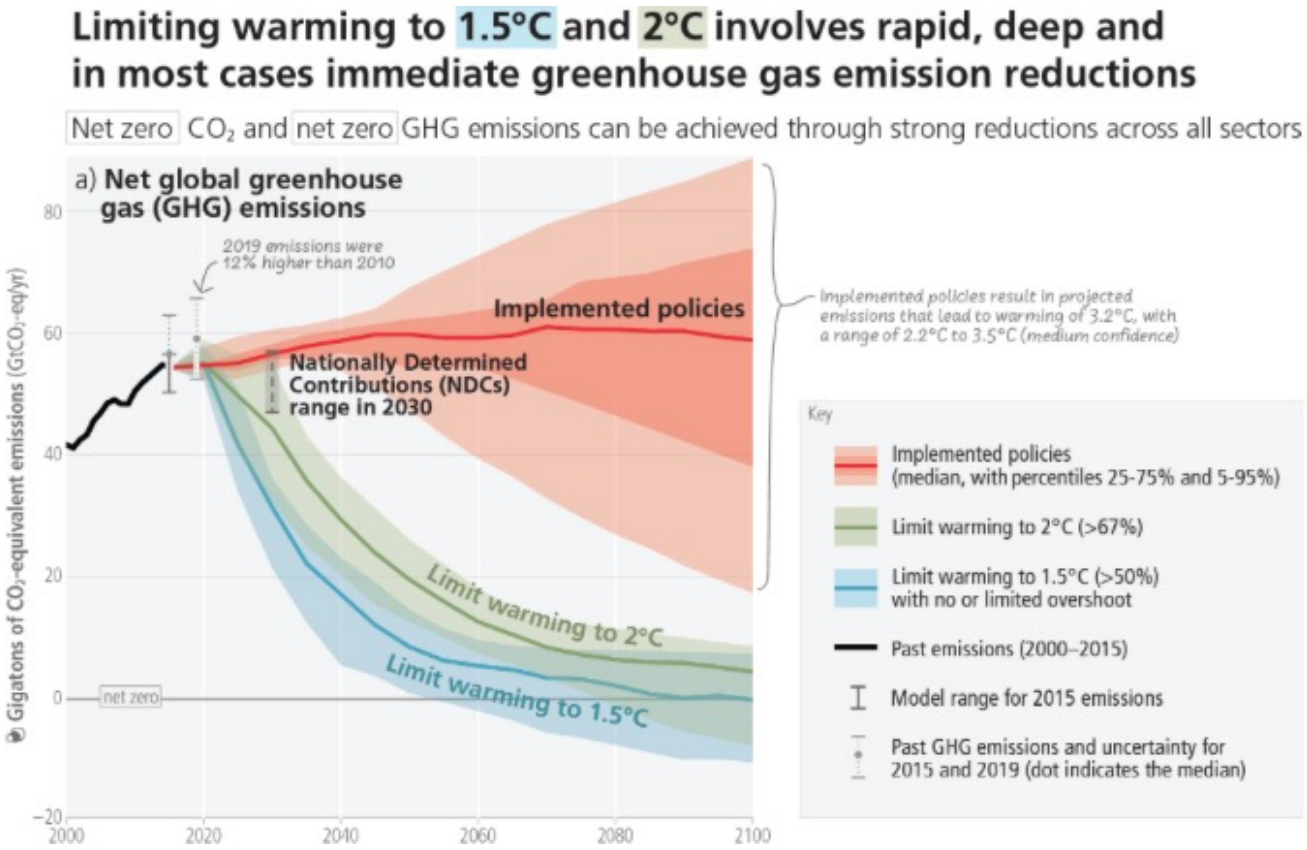
@resimaier, Pixabay

@Coleur, Pixabay

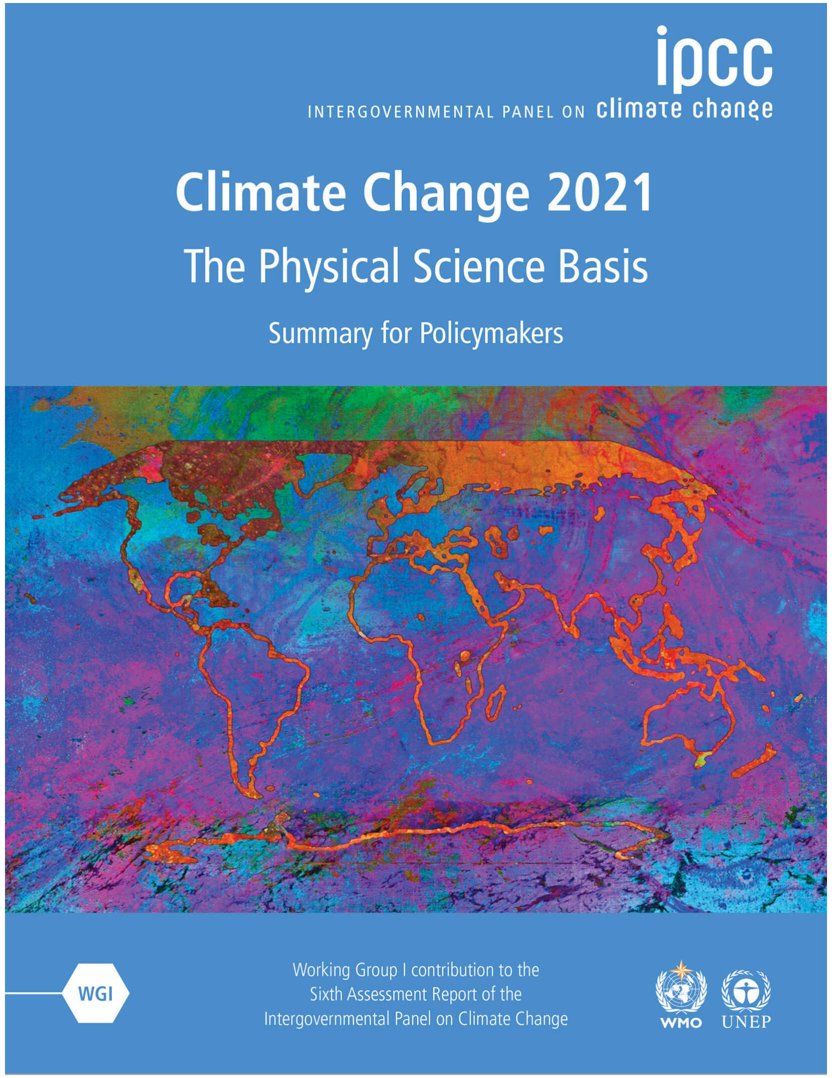
@cgcolman, Pixabay

August 9, 2021

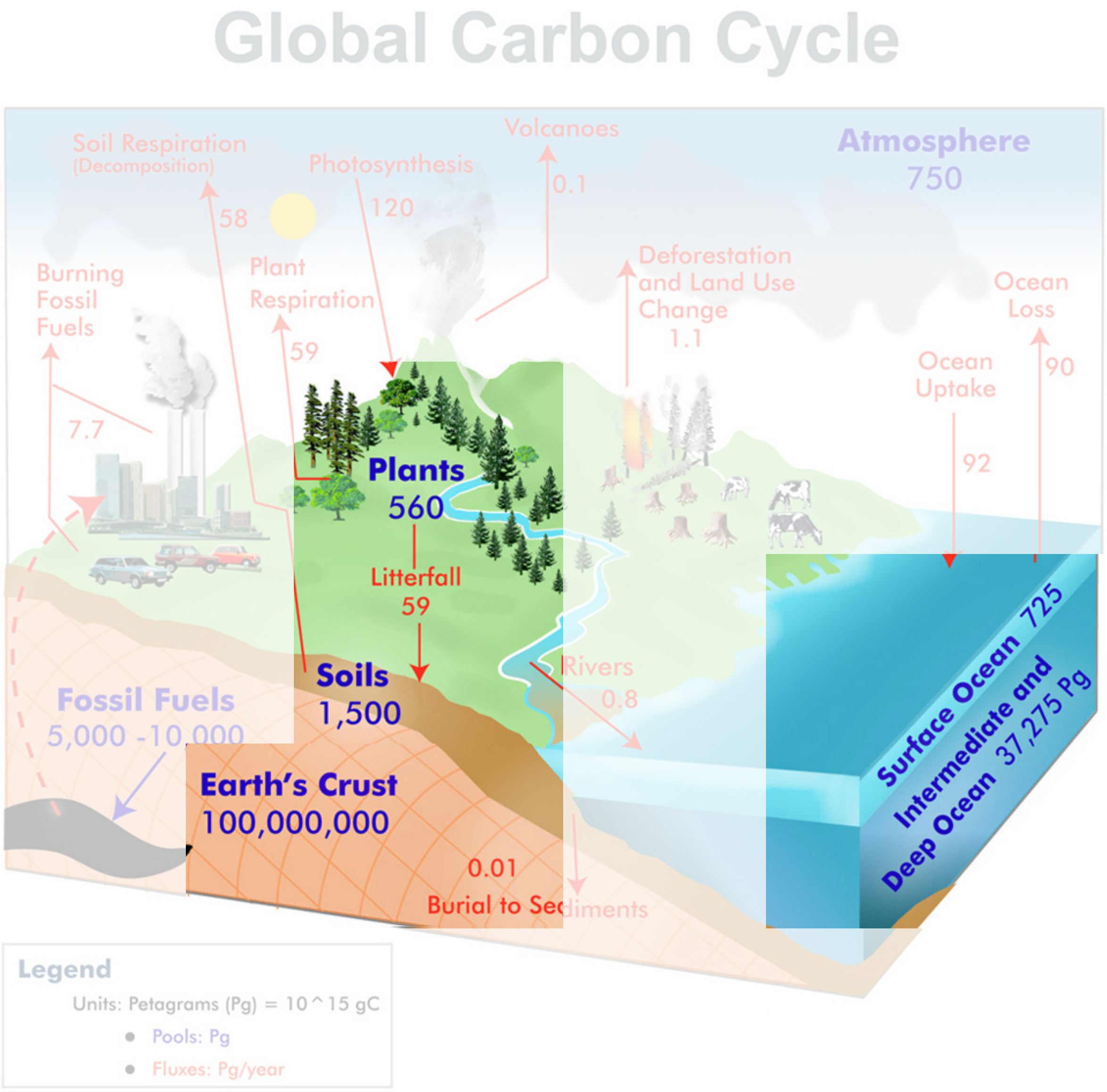




August 9, 2021



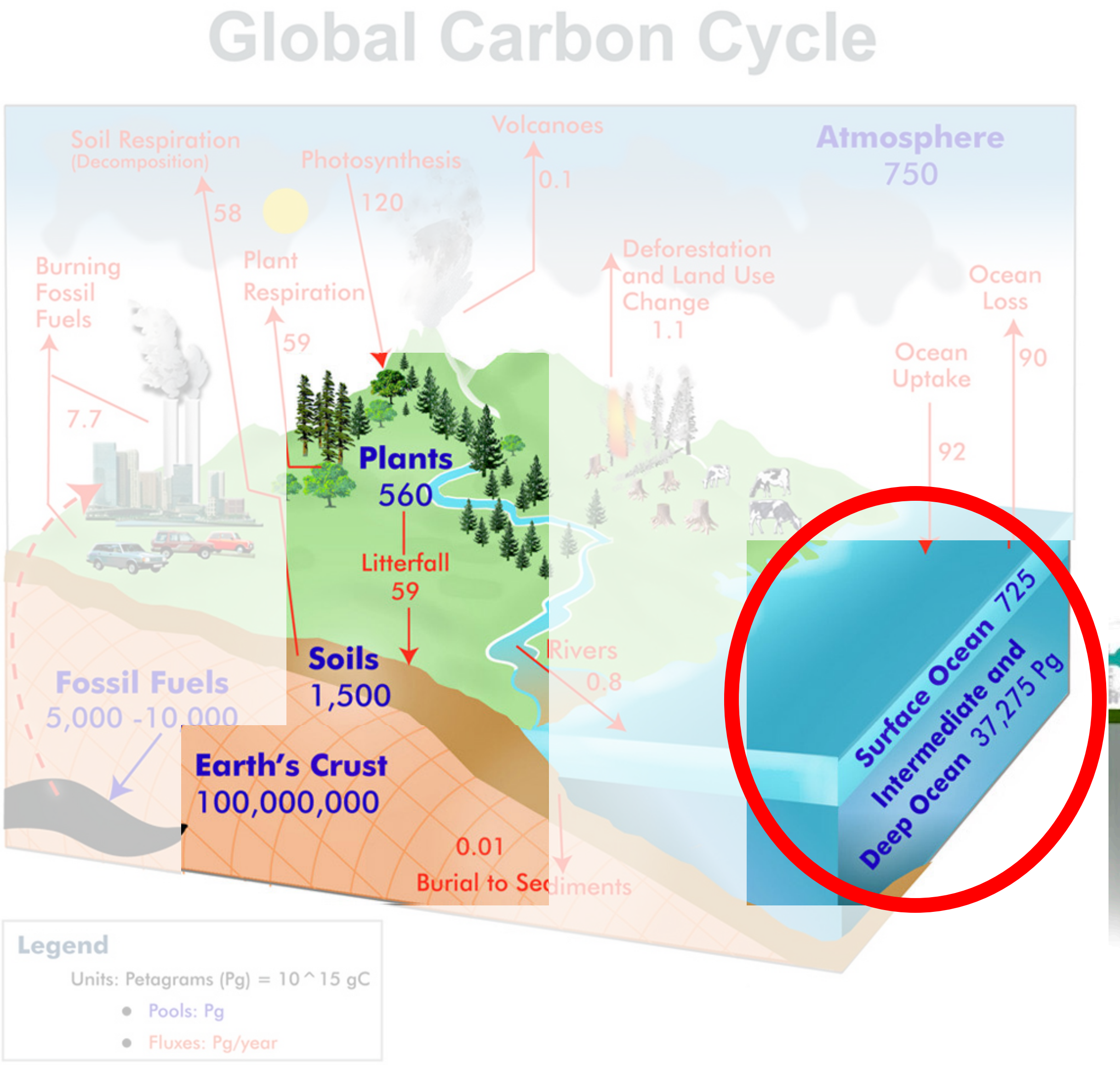
"All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 GtCO2 over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (*high confidence*)."



Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

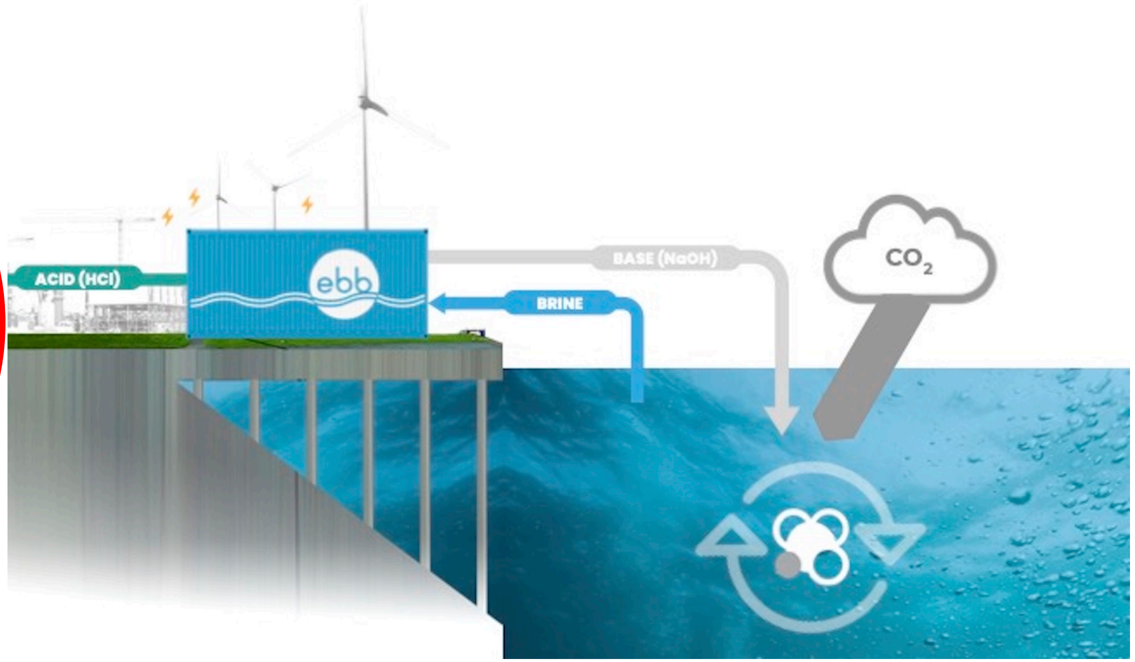
Where can we put all this atmospheric CO_2?

[= climate mitigation]

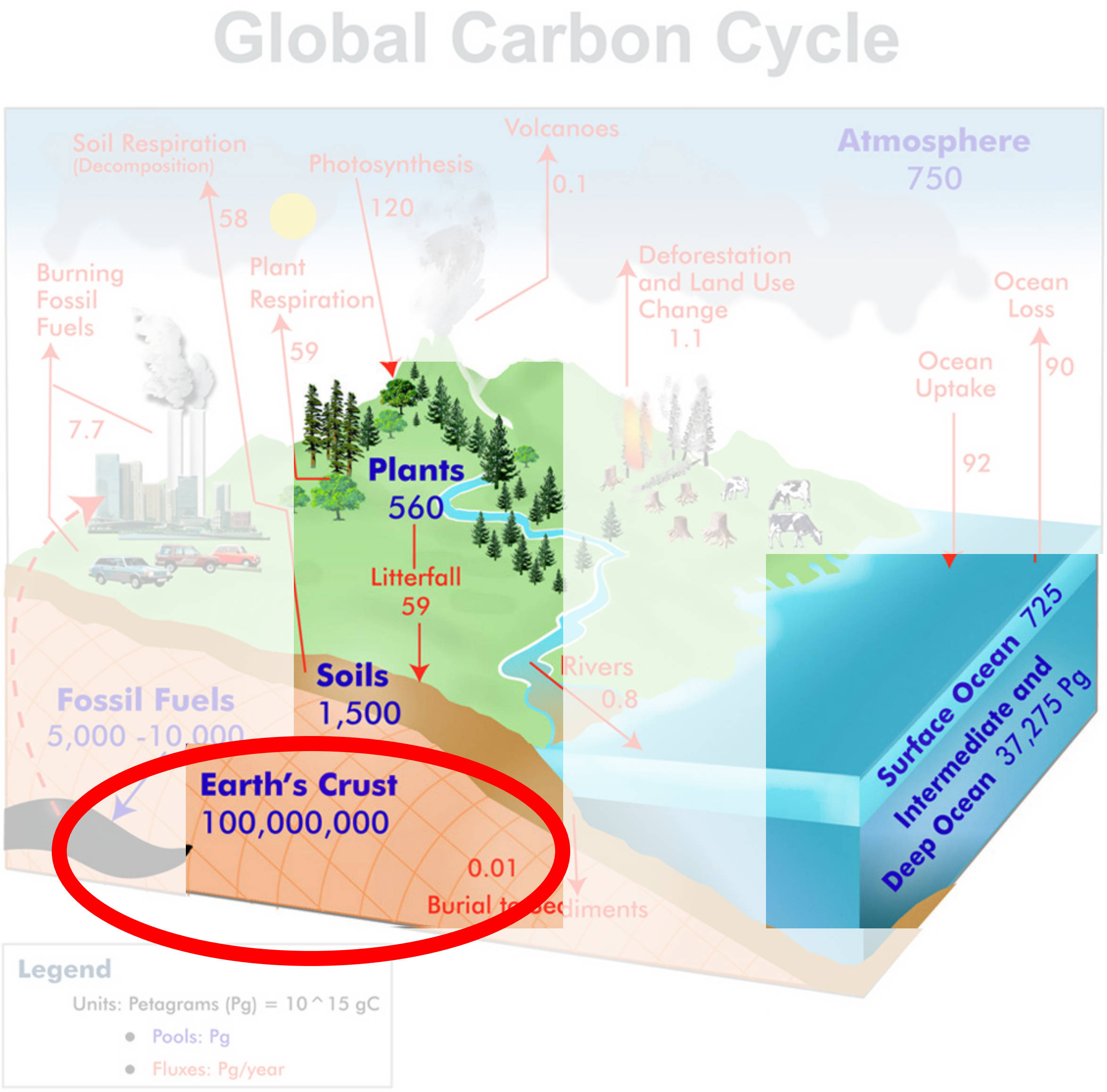


Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

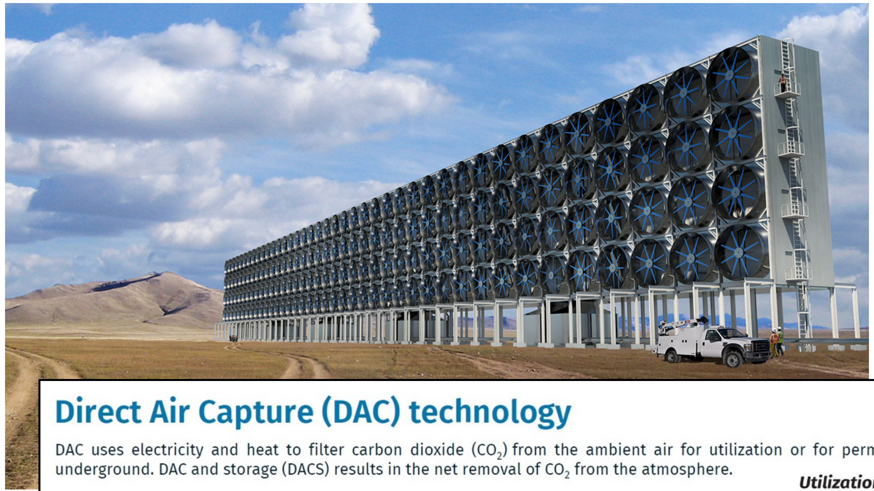
ebb carbon

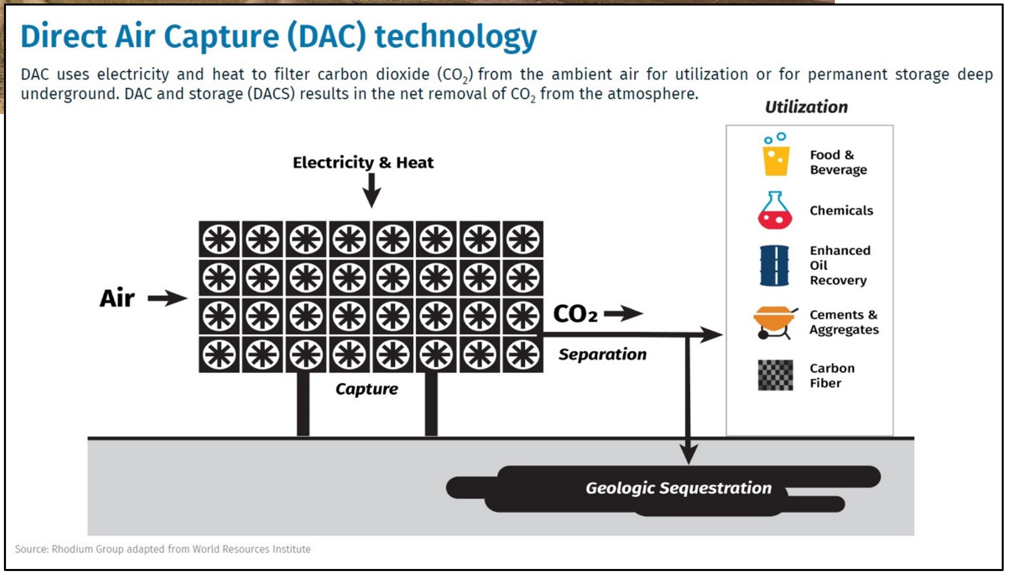


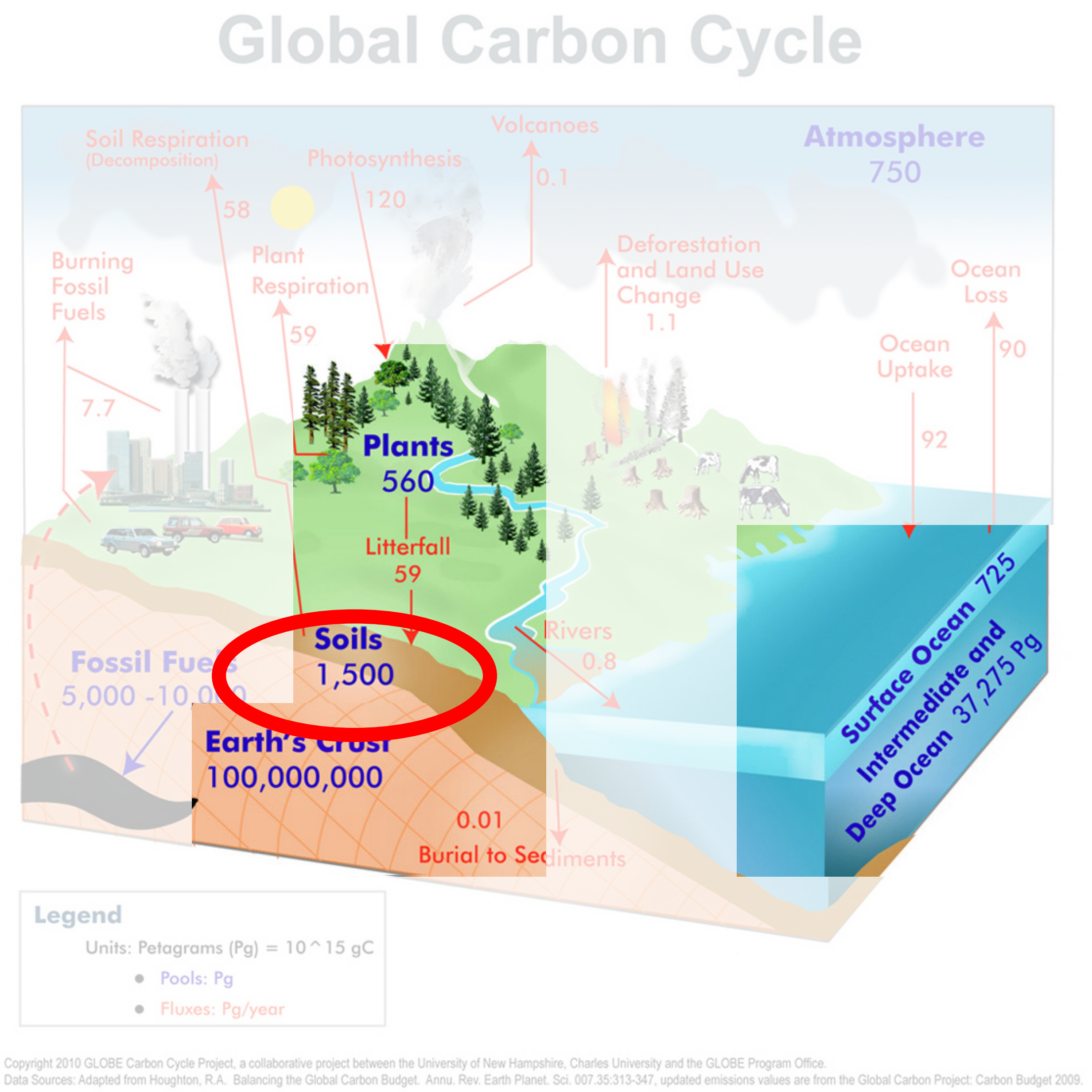
Where can we put all this atmospheric CO_2?



Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

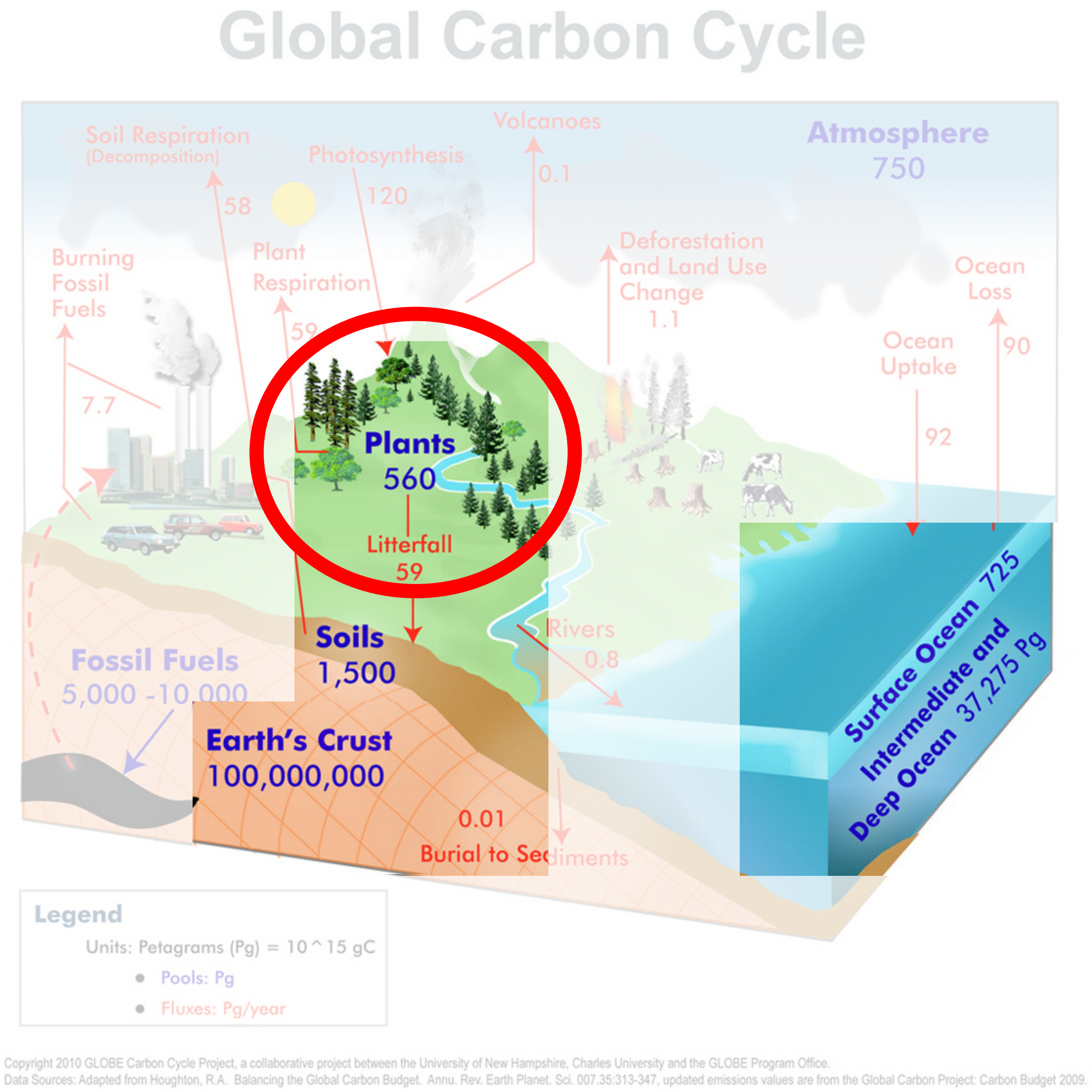






Where can we put all this atmospheric CO_2?

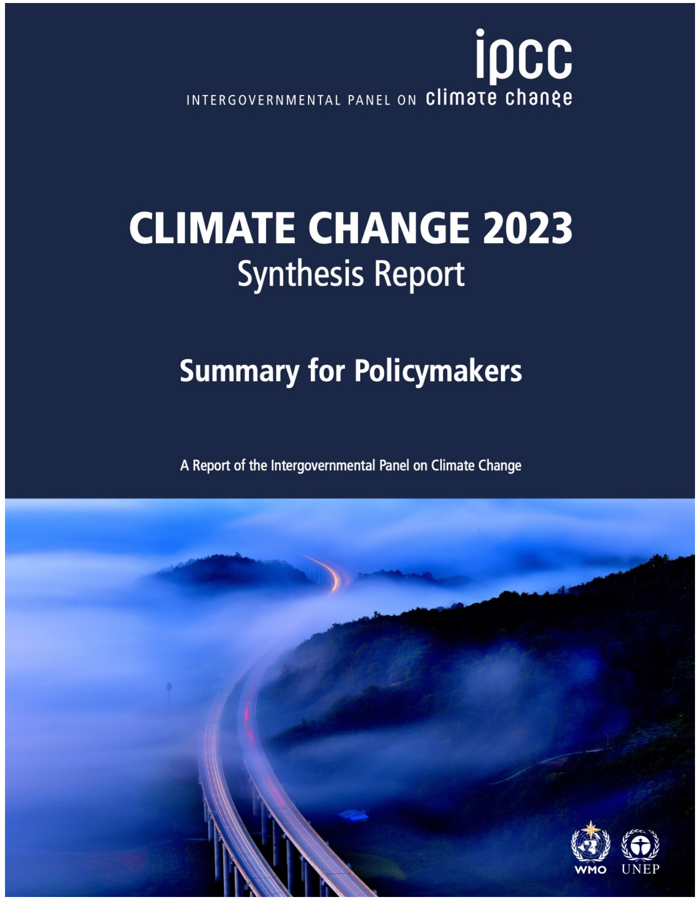
Photo by Josh Berendes on Unsplash



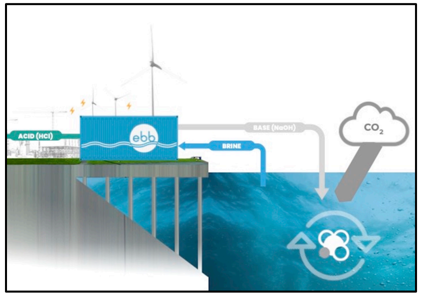
Where can we put all this atmospheric CO_2?

BrineStans @ Wikimedia Commons

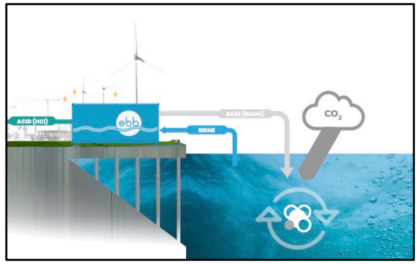
National and international discussions are considering 'forest carbon management' as a pillar of climate mitigation

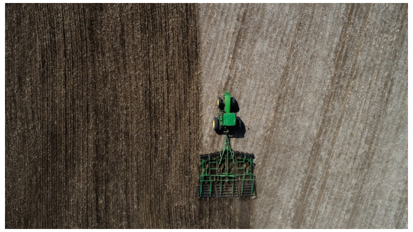


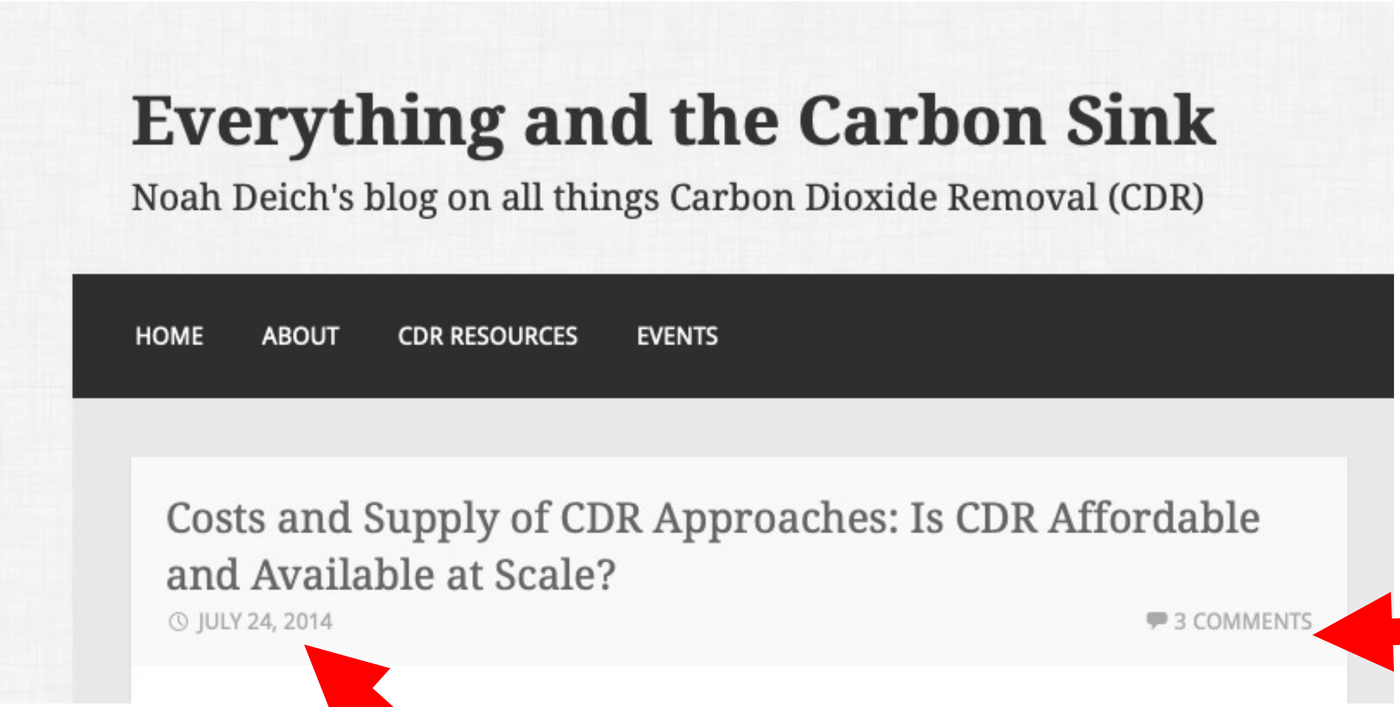
"Rapid and far-reaching transitions across all sectors and systems are necessary to achieve deep and sustained emissions reductions and secure a liveable and sustainable future for all. **These system transitions involve a significant upscaling of a wide portfolio of mitigation and adaptation options.** Feasible, effective, and low-cost options for mitigation and adaptation are already available, with differences across systems and regions. (*high confidence*)"



Gosh – I wish we didn’t have to have these conversations…







Everything and the Carbon Sink

Noah Deich's blog on all things Carbon Dioxide Removal (CDR)

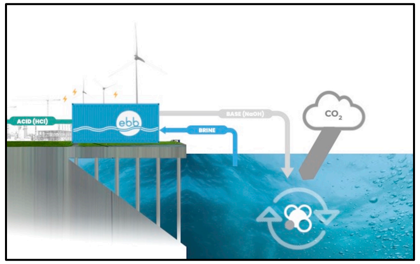
HOME ABOUT CDR RESOURCES EVENTS

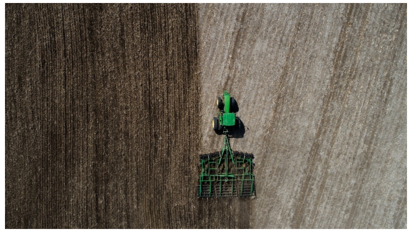
Costs and Supply of CDR Approaches: Is CDR Affordable and Available at Scale?

JULY 24, 2014 3 COMMENTS

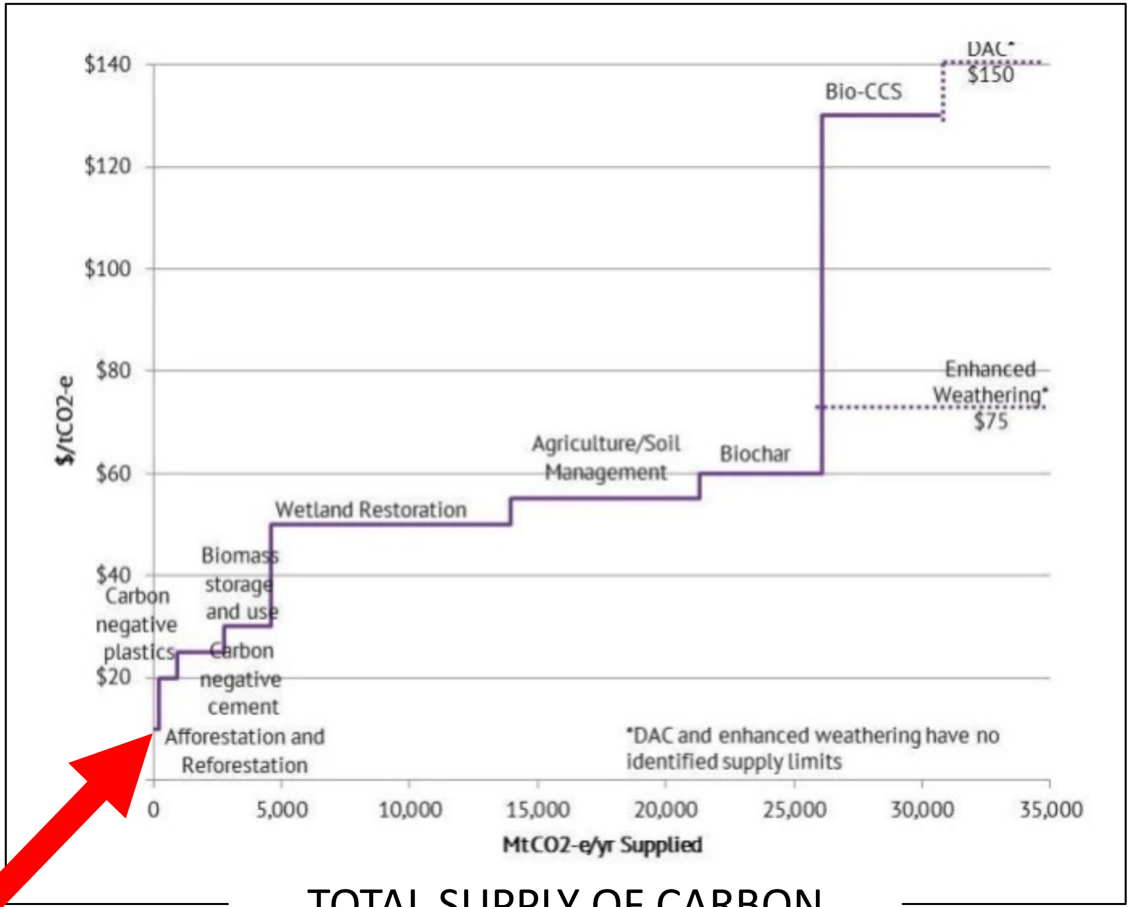
“If we (very) aggressively cut greenhouse gas emissions over the next decades, we can obviate the need for large-scale carbon dioxide removla altogether.”

Relative to other carbon dioxide removal strategies, forest carbon removal is cheap, but limited





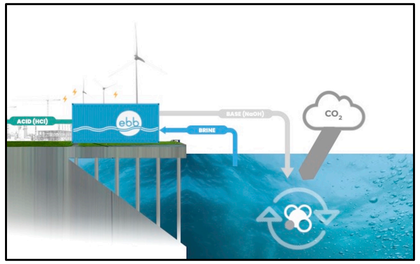
COST OF 1 TONNE CO_2)

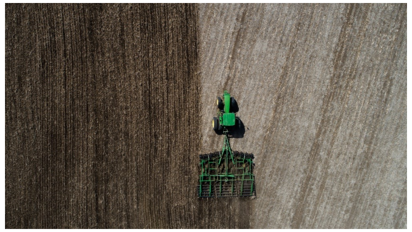


TOTAL SUPPLY OF CARBON
(TONNES CO_2 PER YEAR)

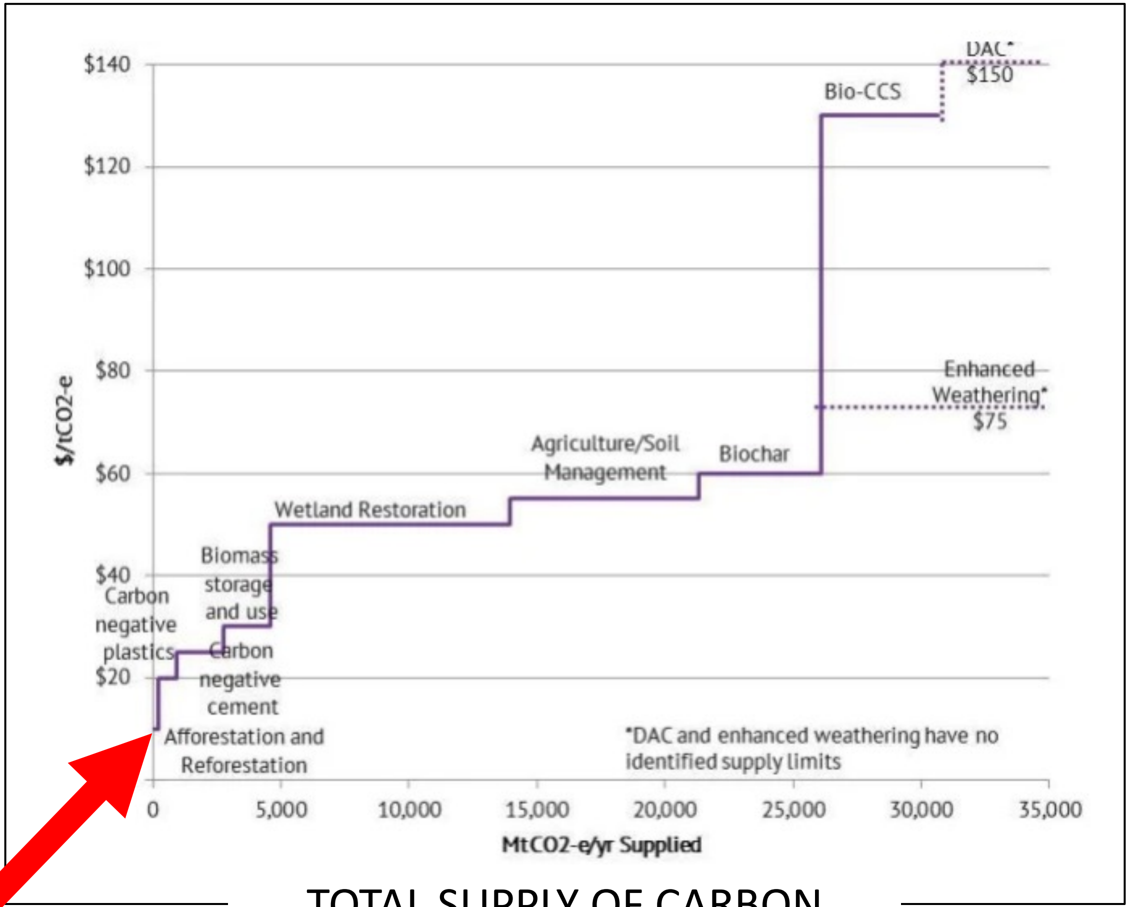
Diech 2014, https://carbonremoval.wordpress.com/

Relative to other carbon dioxide removal strategies, forest carbon removal is cheap, but limited





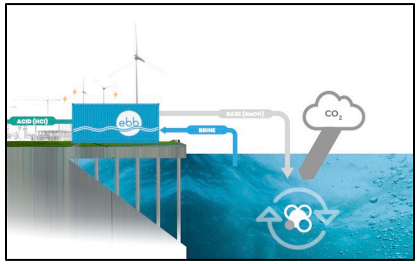
COST OF 1 TONNE CO_2)

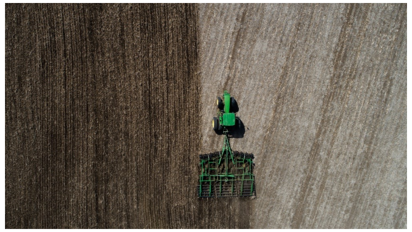


TOTAL SUPPLY OF CARBON
(TONNES CO_2 PER YEAR)

Diech 2014, https://carbonremoval.wordpress.com/

There are strong and divergent opinions about the role of forests for climate mitigation





The Washington Post
Democracy Dies in Darkness

ENERGY

Mother Nature Has the Best Climate-Fixing Technology

Analysis by Amanda Little | Bloomberg
February 20, 2023 at 4:03 p.m. EST

CALIFORNIA HOT SPRINGS, CA - SEPTEMBER 21: The tree where President Bill Clinton invoked the Antiquities Act of 1906 and created the Giant Sequoia National Monument is seen as the Windy Fire blazes through the Long Meadow Grove of giant sequoia trees near The Trail of 100 Giants overnight in Sequoia National Forest on September 21, 2021 near California Hot Springs, California. This Sequoia is about 2,00 years old and is 245 feet tall, 62 feet around and 18 feet in diameter. Barn scar on this tree are hundreds of years old. As climate

The New York Times

SUBSCRIBER-ONLY NEWSLETTER
David Wallace-Wells

OPINION

Forests Are No Longer Our Climate Friends

Sept. 6, 2023

Illustration by Sam Whitney/The New York Times; photographs by Chris Hellier and georgeclerk/Getty Images

Disclaimer: Carbon should probably not be the *primary* reason to manage forests.

The New York Times

SUBSCRIBER-ONLY NEWSLETTER
David Wallace-Wells

OPINION

Forests Are No Longer Our Climate Friends

Sept. 6, 2023

Illustration by Sam Whitney/The New York Times; photographs by Chris Hellier and georgeclerk/Getty Images

When carbon is viewed as the primary reason to think about forests . . .

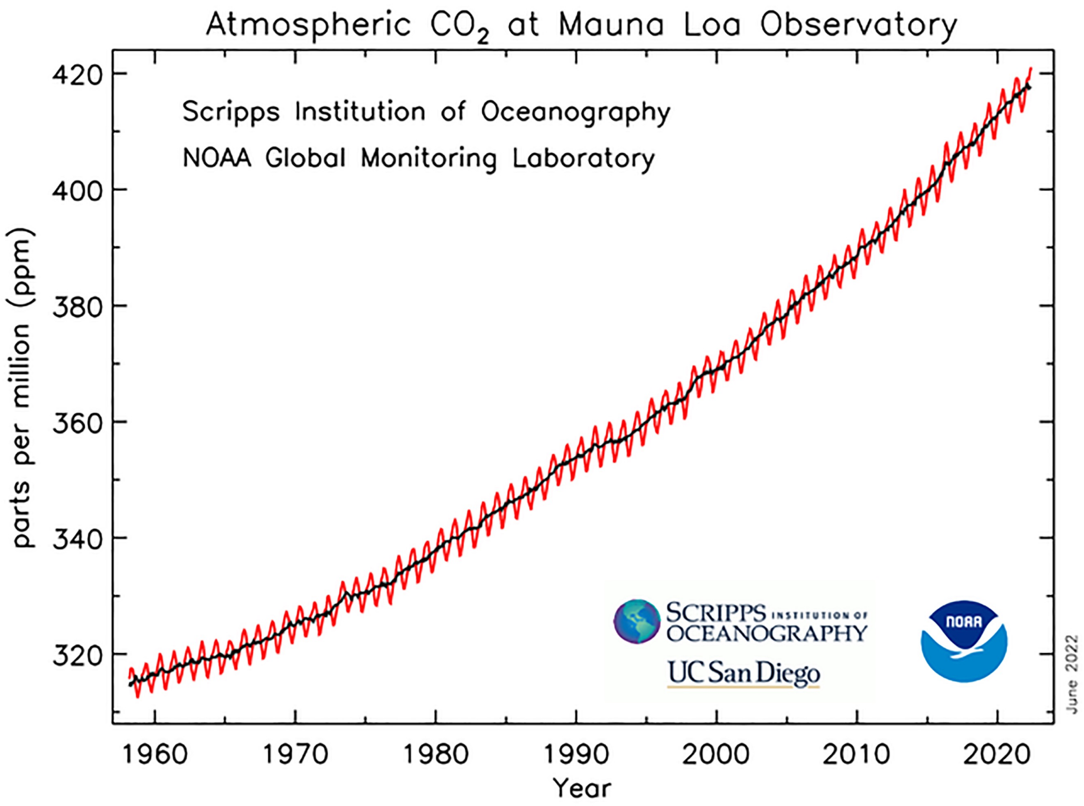
it's easy to conclude that there is no hope and that we should not expend resources on forest management.

Why carbon, forests, and climate are deeply entwined.

[or, an overview of forest carbon cycling]

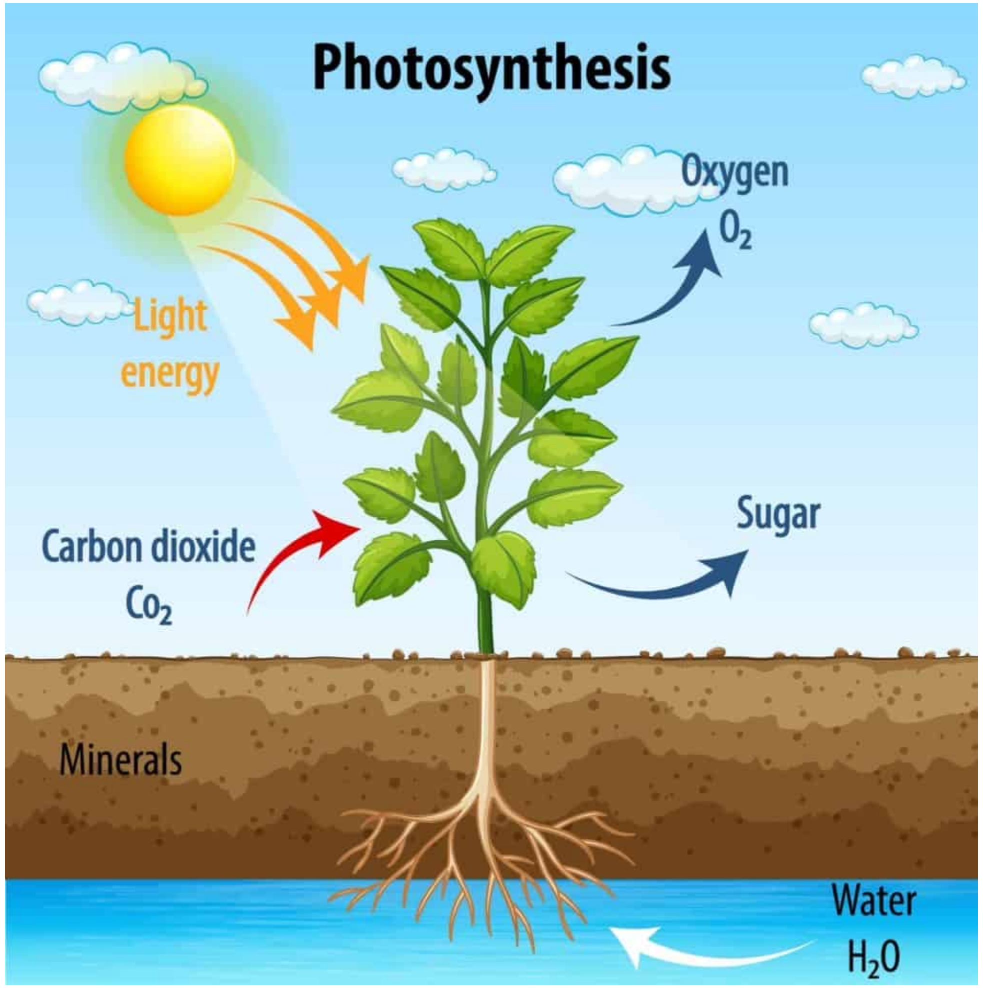
Forests are highly-evolved, sophisticated 'direct air capture' facilities

Forests are highly-evolved, sophisticated 'direct air capture' facilities



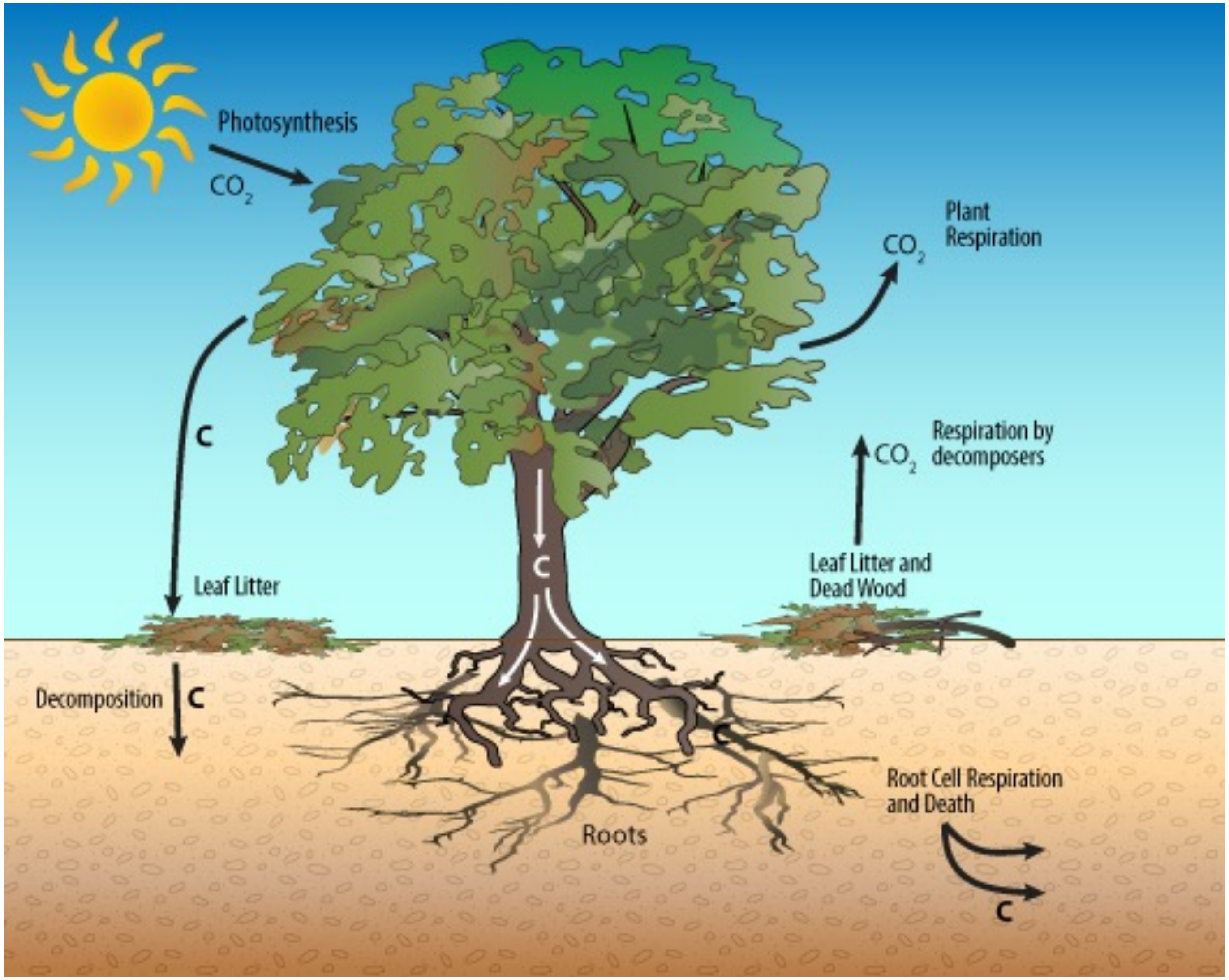
BotMultifhill @ Wikimedia Commons

Forest vegetation removes carbon dioxide from the atmosphere using 100% renewable solar energy

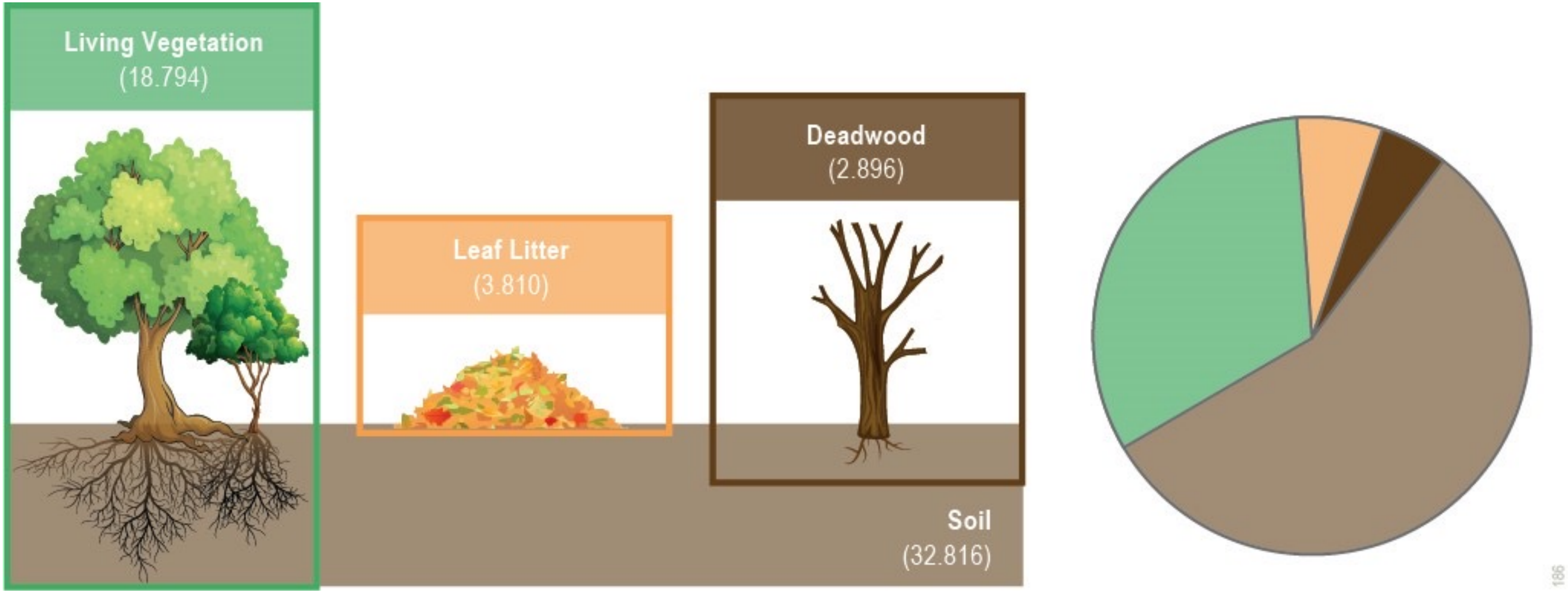


https://bartonhillfarms.com/photosynthesis-for-kids/

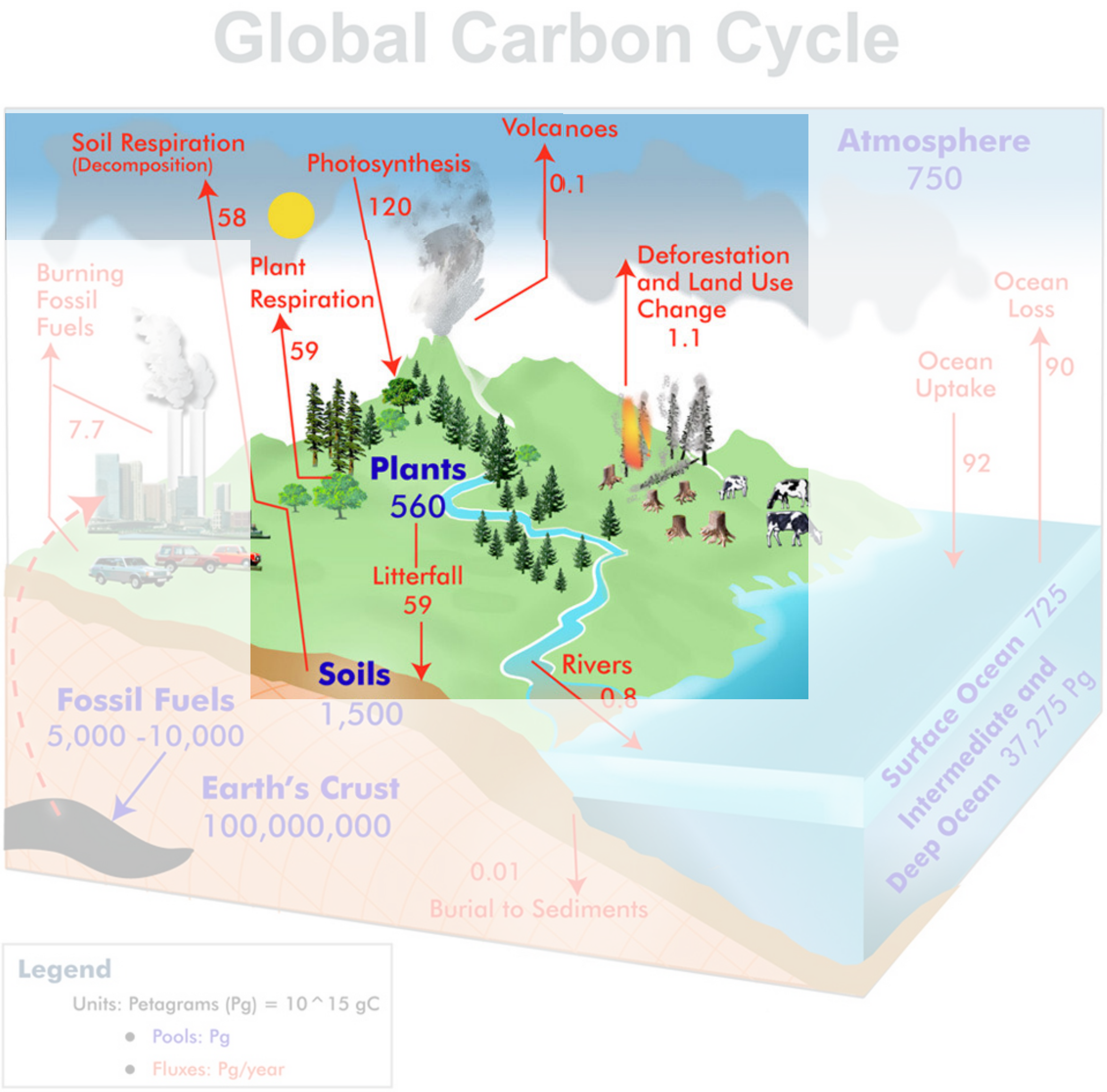
Forests transfer carbon from plant tissues into soils



Here in the United States, we estimate that forests currently store 58.32 billion tonnes of carbon

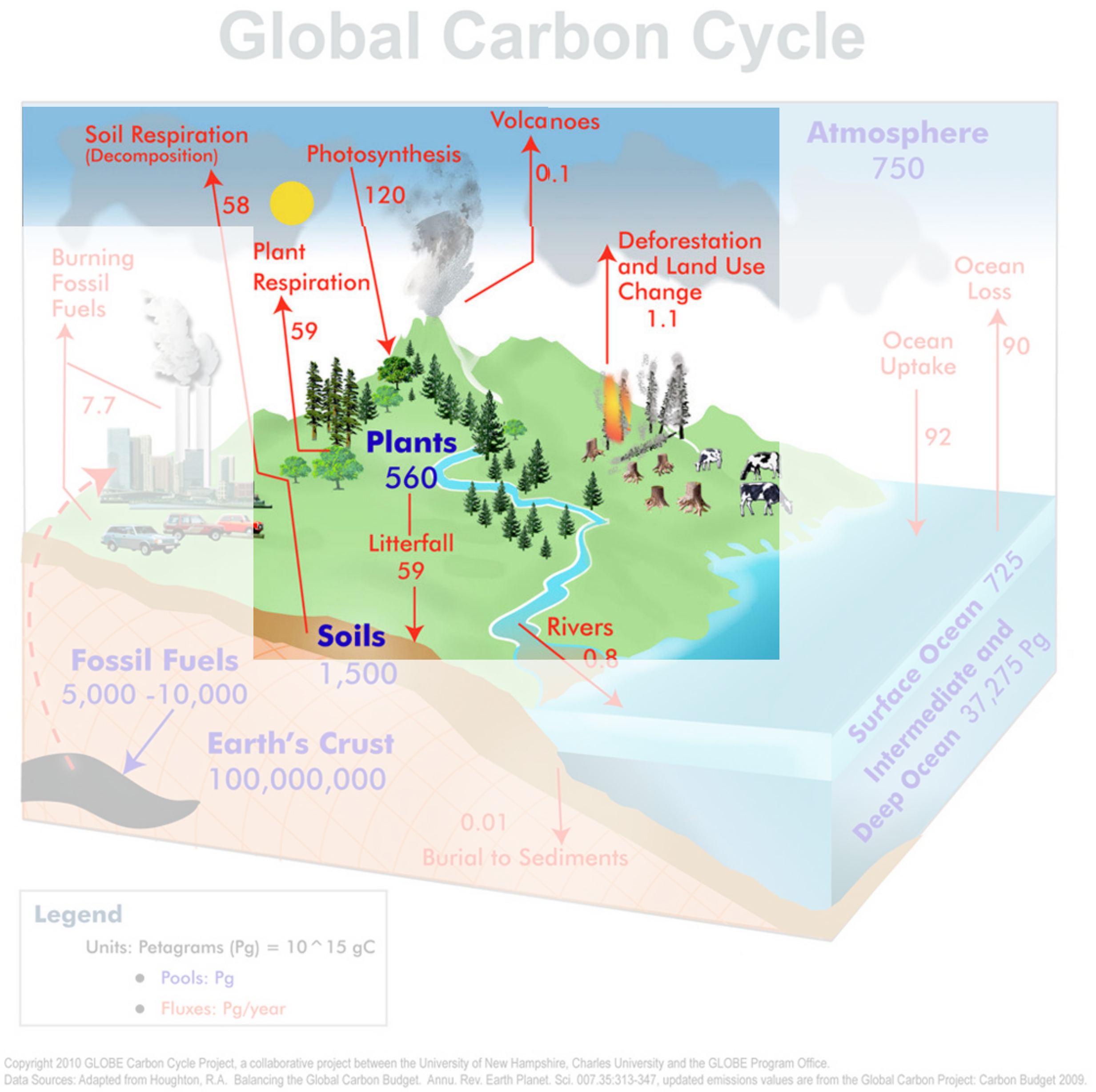


US EPA. 2021. US Greenhouse Gas Reporting Program

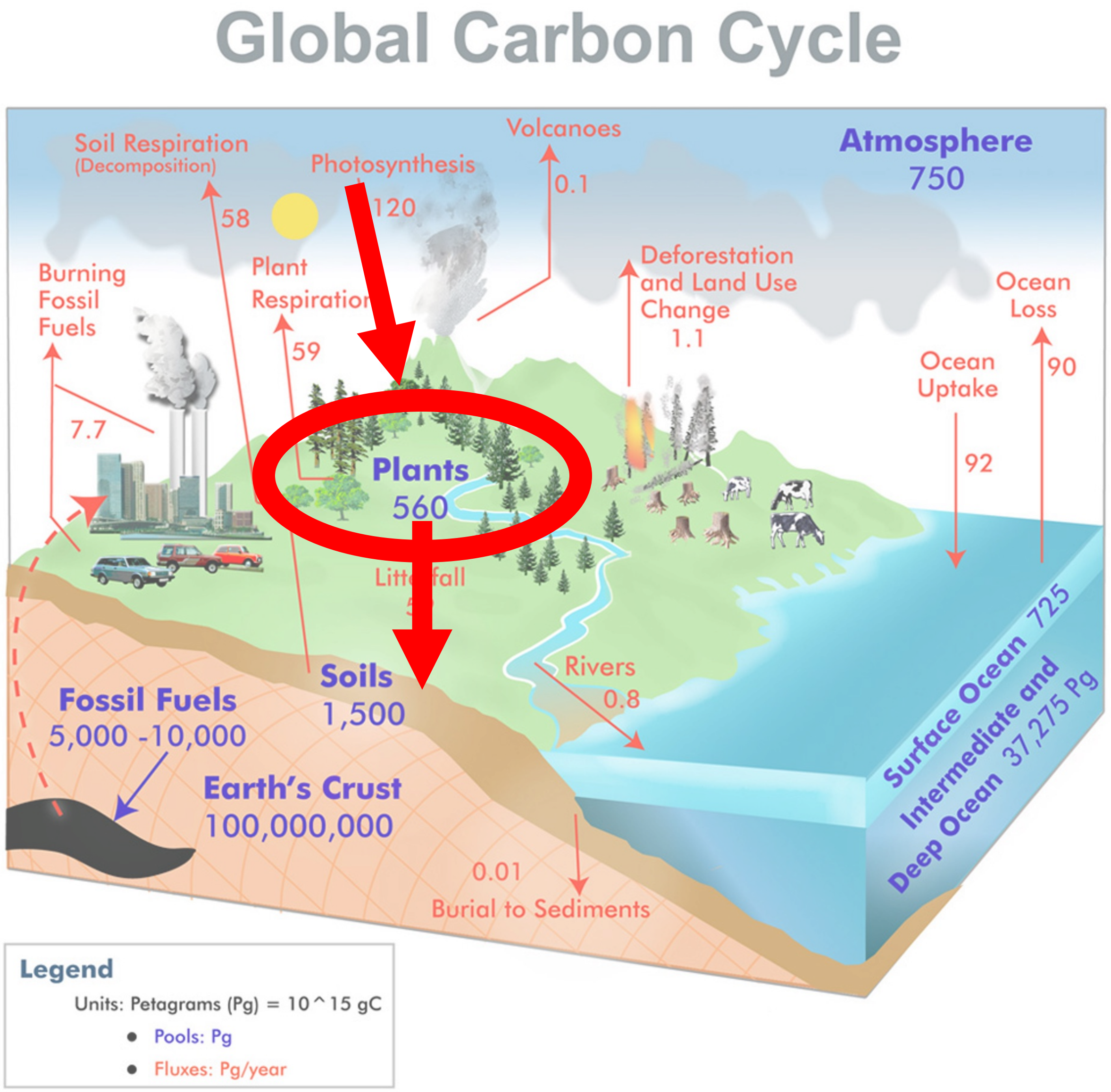


Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

Forest ecosystems are *dynamic* carbon storage facilities



Regardless of whether forests are part of the "carbon dioxide removal" portfolio – forest carbon is a huge part of the carbon budget!

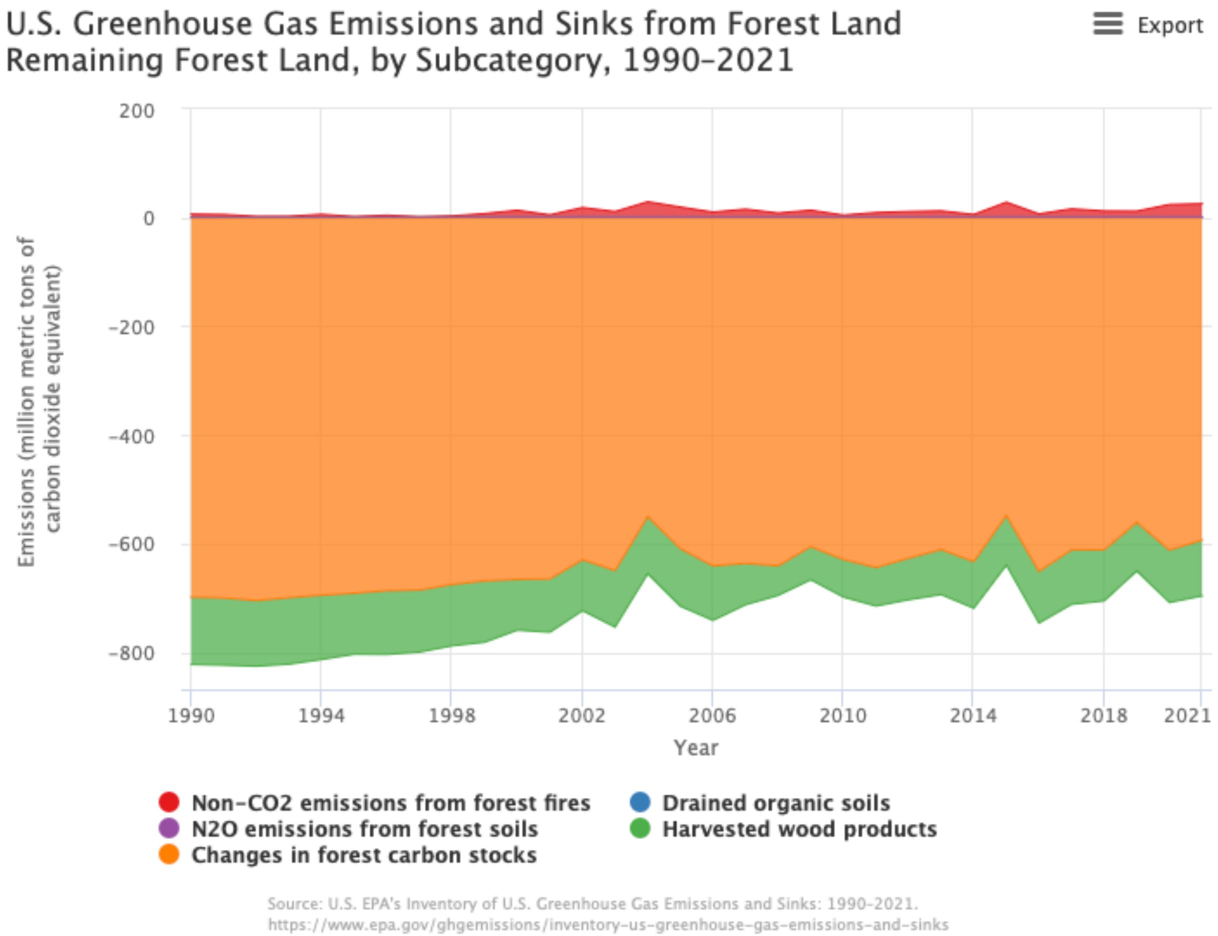


Data Sources: Adapted from Houghton, R.A. Balancing the Global Carbon Budget. Annu. Rev. Earth Planet. Sci. 007.35:313-347, updated emissions values are from the Global Carbon Project: Carbon Budget 2009.

Historically, forests are a net carbon sink each year

[CO_2 removal > CO_2 emissions]

Historically, forests are a net carbon sink each year [CO_2 removal > CO_2 emissions]



Percent change:

1990–2021

Non-CO2 emissions from forest fires:
Emissions ▲ 341.4%

Drained organic soils:
No change

N2O emissions from forest soils:
Emissions ▲ 455.1%

Harvested wood products:
Sink ▼ 16.9%

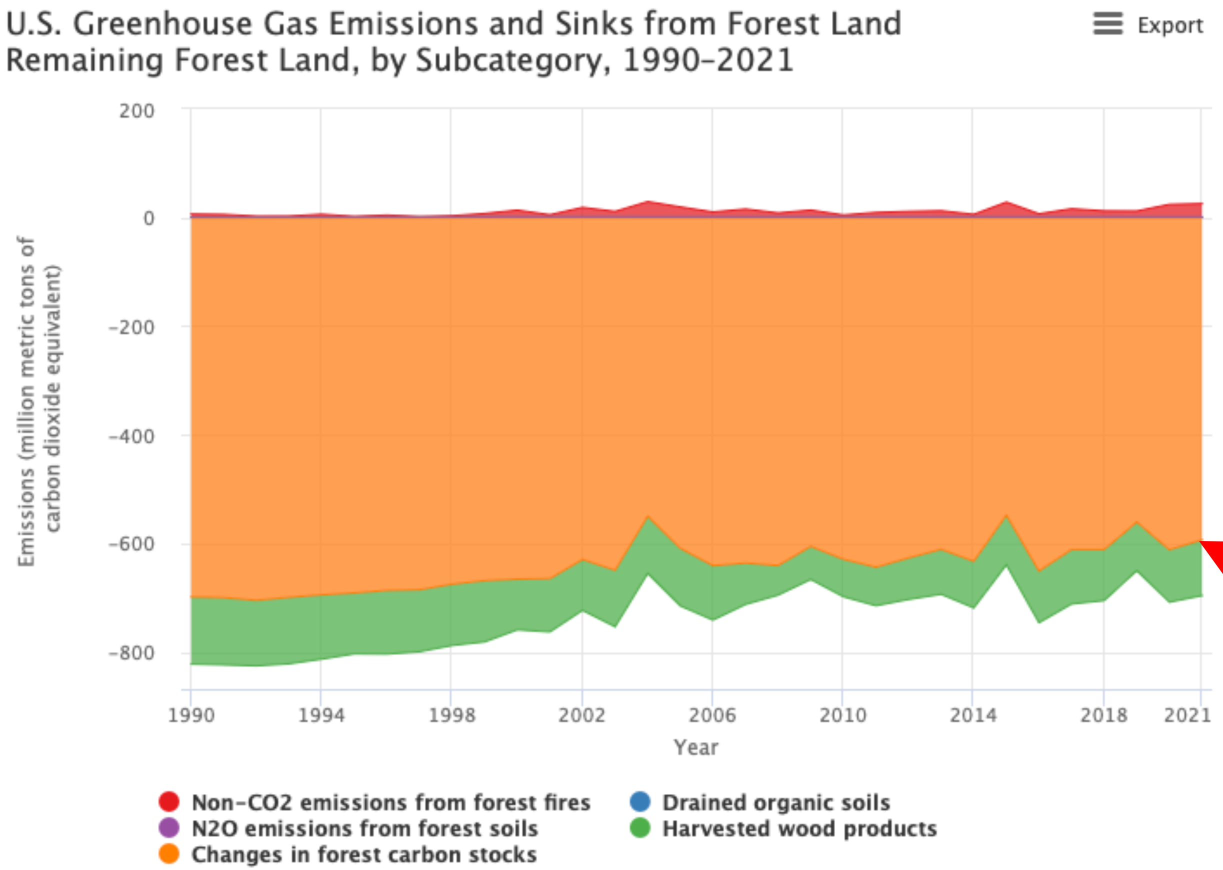
Changes in forest carbon stocks:
Sink ▼ 15.1%

Net total: Sink ▼ 17.8%

https://www.epa.gov/ghgreporting

US EPA. 2021. US Greenhouse Gas Reporting Program

In 2021, US forest captured ~ 593 MMT CO_2e



Source: U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

Percent change:

1990–2021

Non-CO2 emissions from forest fires:
Emissions ▲ 341.4%

Drained organic soils:
No change

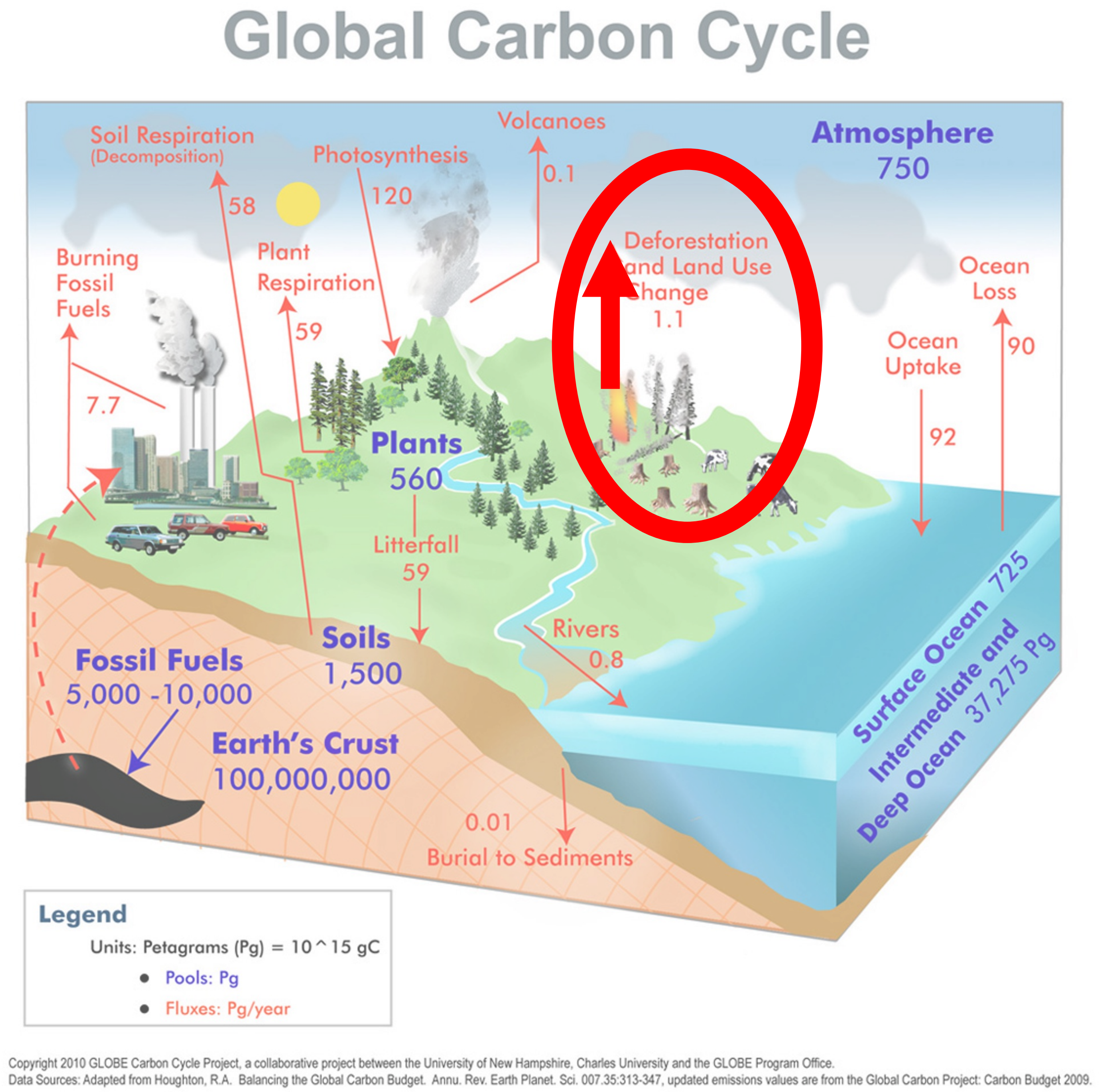
N2O emissions from forest soils:
Emissions ▲ 455.1%

Harvested wood products:
Sink ▼ 16.9%

Changes in forest carbon stocks:
Sink ▼ 15.1%

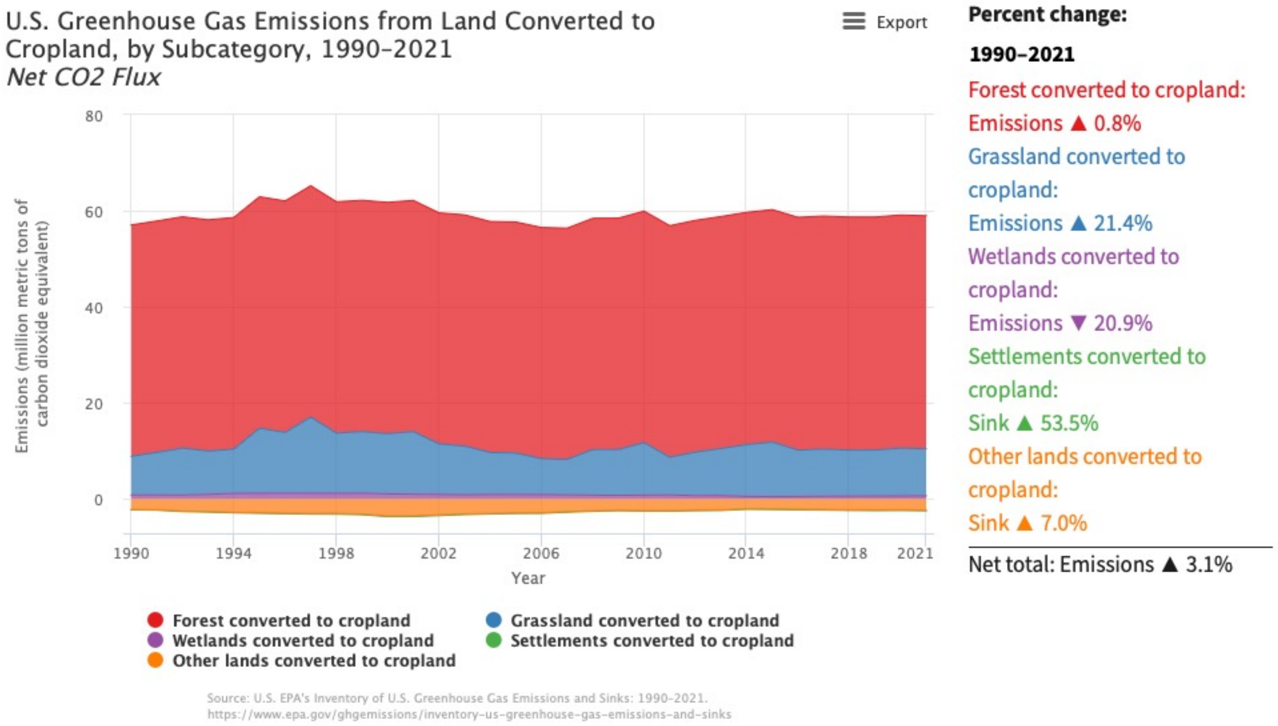
Net total: Sink ▼ 17.8%

https://www.epa.gov/ghgreporting



Forests emit carbon dioxide when they are disturbed or converted to other land uses

Forests emit carbon dioxide when they are converted to other land uses



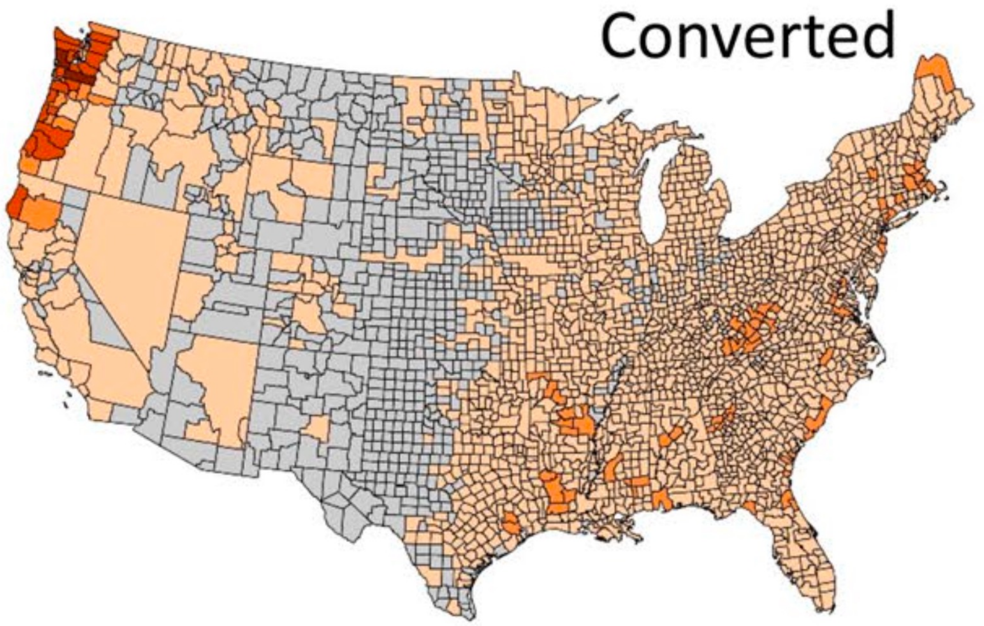
https://www.epa.gov/ghgreporting

US EPA. 2021. US Greenhouse Gas Reporting Program

Avoided forest conversion

Historical annual carbon emissions from forest conversion range from 22-125 MMT CO_2 per year

Source	Area (Mha per year)	Forest Emissions (MMT CO_2 per year)	Key Regions of Opportunity
Harris et al. 2016	0.1	22 ± 3.67	Pacific Northwest, eastern urban population centers
US EPA 2021	--	125.3 in 2021	---



Harris et al. 2016, *Carbon Balance and Management,* DOI 10.1186/s13021-016-0066-5

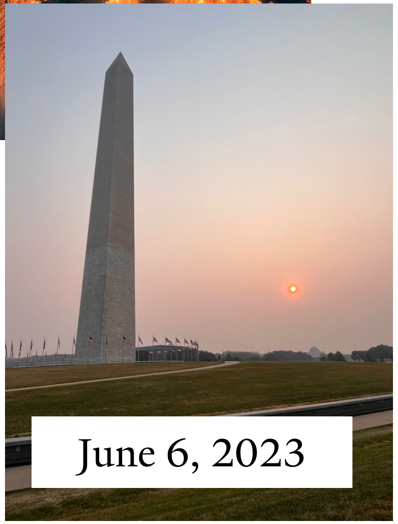
Forests emit carbon dioxide when they are disturbed

@CharlVera, Pixabay

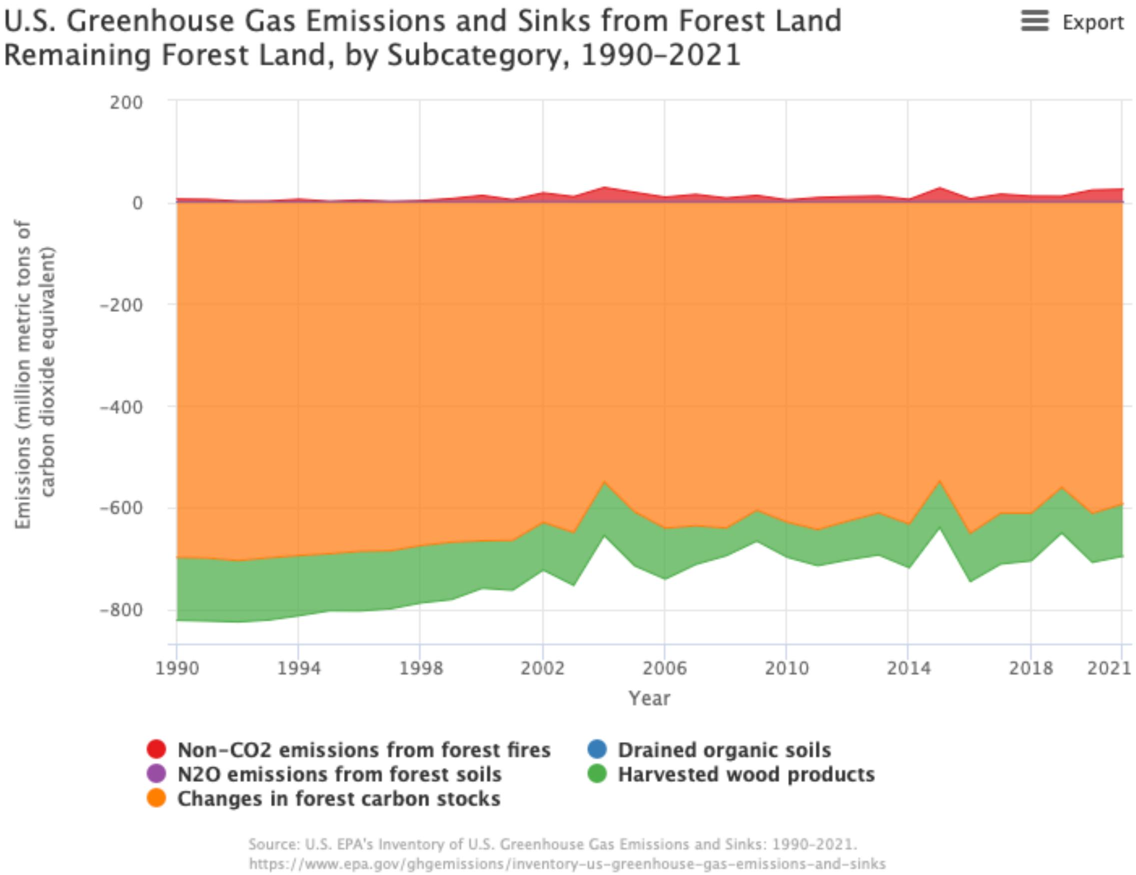
@Matt Pardue, Wikimedia Commons

@K Dodd, Wikimedia Commons

Wildfire in the US is leading cause of current forest fire emissions, with ~ 120 MMT of forest CO_2e per year (2016-2020)



June 6, 2023



Percent change:

1990–2021

Non-CO2 emissions from forest fires:
Emissions ▲ 341.4%

Drained organic soils:
No change

N2O emissions from forest soils:
Emissions ▲ 455.1%

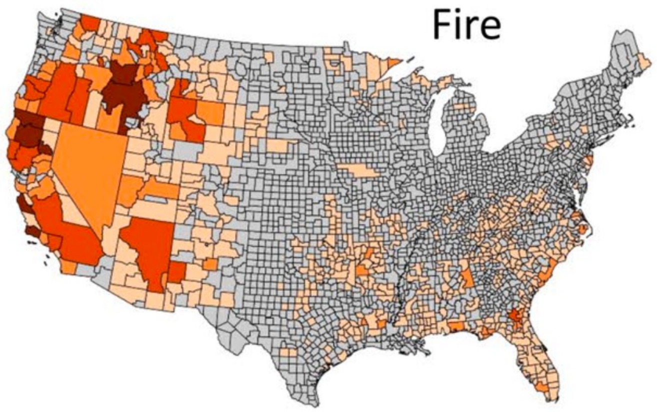
Harvested wood products:
Sink ▼ 16.9%

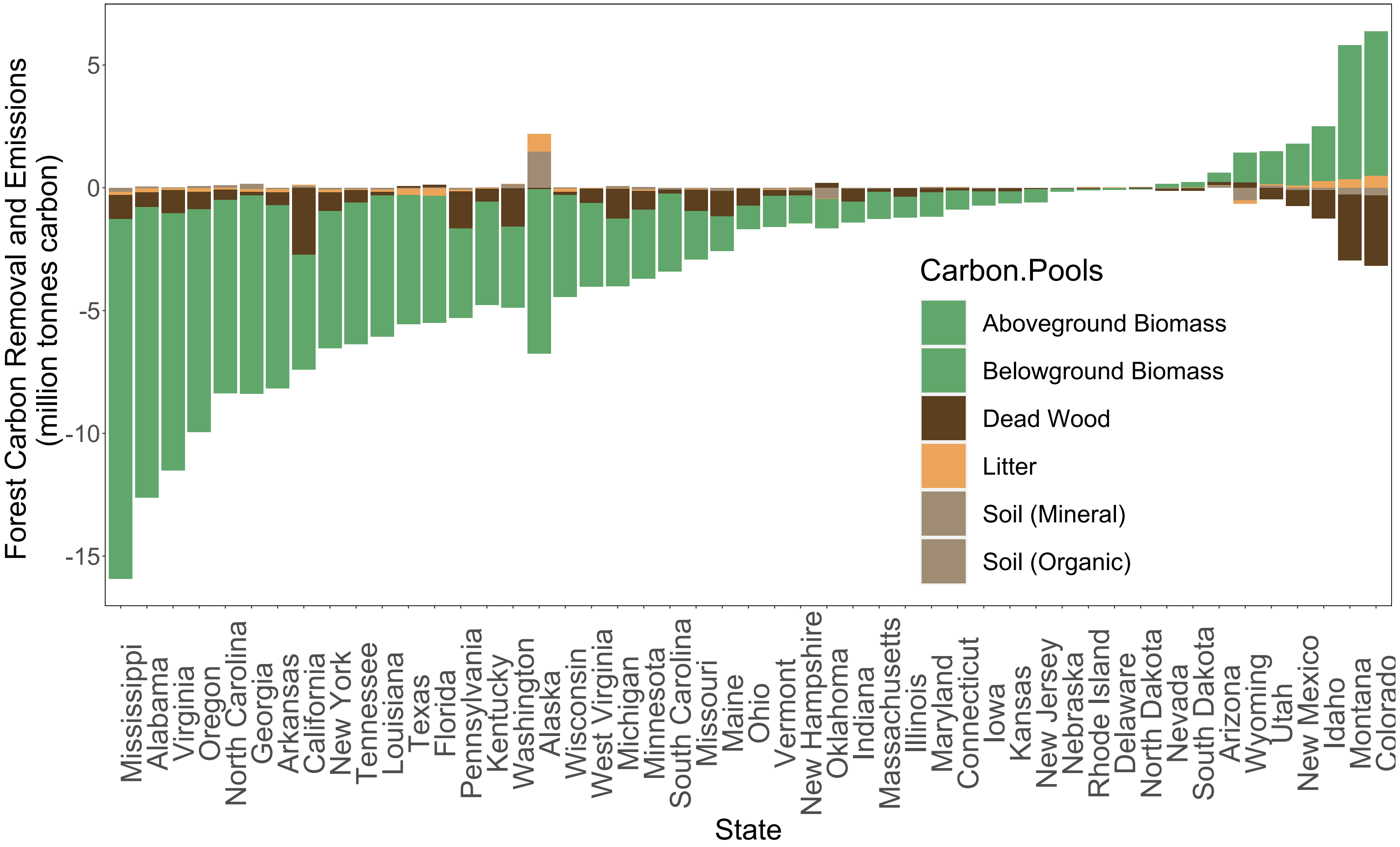
Changes in forest carbon stocks:
Sink ▼ 15.1%

Net total: Sink ▼ 17.8%

https://cfpub.epa.gov/ghgdata/inventoryexplorer/

Wildfire in the US is leading cause of current forest fire emissions, with ~ 120 MMT of forest CO_2e per year (2016-2020)

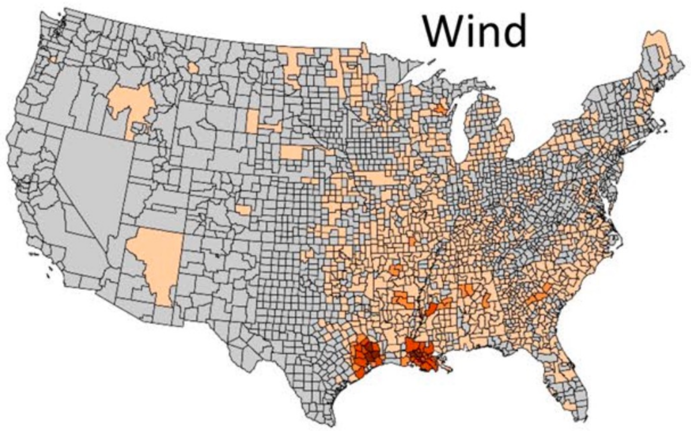




Harris et al. 2016, *Carbon Balance and Management,*
DOI 10.1186/s13021-016-0066-5

https://www.epa.gov/ghgreporting

Tree mortality from hurricanes emit an average of 18 - 66 MMT of forest CO_2 per year



Harris et al. 2016, *Carbon Balance and Management,* DOI 10.1186/s13021-016-0066-5

Table 1 | Ten most destructive hurricane events with dates and categories at landfalling. Numbers in parentheses show minimum and maximum range

Name	Landfalling Date	Category at Landfalling*	Biomass mortality (TgC)
Camille	8/15/1969	5	59.49 (41.42 ~ 77.58)
Donna	9/10/1960	4	51.48 (35.80 ~ 67.16)
Hazel	10/15/1954	4	47.39 (32.27 ~ 62.51)
Okeechobee	9/17/1928	4	41.22 (28.78 ~ 53.69)
Elena	9/1/1985	3	38.42 (26.98 ~ 49.86)
Katrina	8/29/2005	3	36.03 (27.75 ~ 46.29)
Gracie	9/29/1959	3	33.85 (23.47 ~ 44.21)
Diana	9/13/1984	3	33.43 (23.18 ~ 43.68)
Hugo	9/22/1989	4	30.47 (20.91 ~ 40.05)
Frederic	9/13/1979	3	30.4 (21.22 ~ 39.58)

*based on Saffir-Simpson scale.

Dahal et al. 2014, , DOI 10.1038/srep05197

Tree mortality from hurricanes on the rise?

Hurricane Research Division
Atlantic Oceanographic & Meteorological Laboratory
National Oceanic & Atmospheric Administration

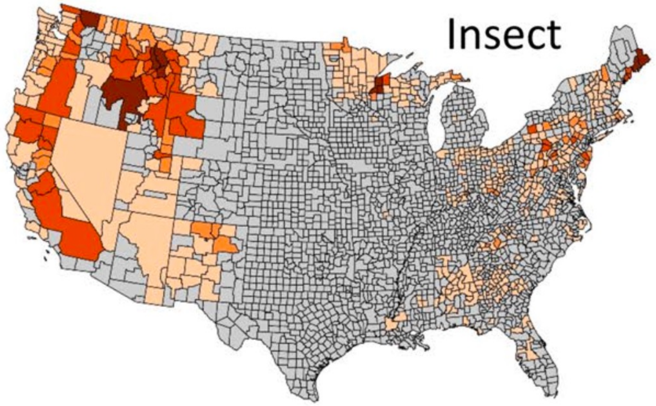
Continental United States Hurricane Impacts/Landfalls 1851-2022

(Revised in April 2023 to add in the 2022 season)

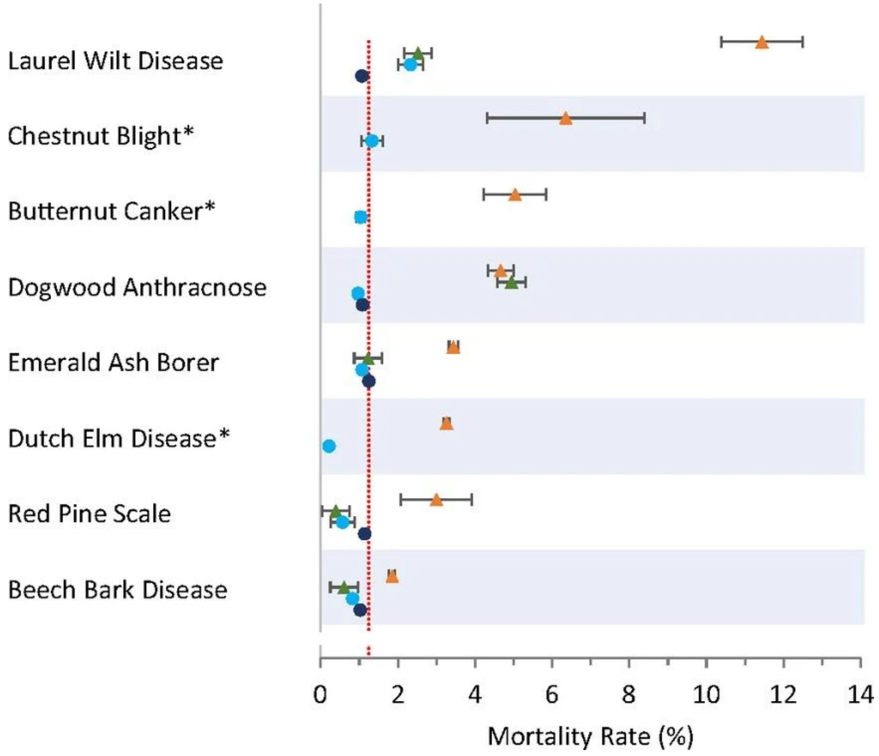
Year	Month	States Affected and Category by States	Highest Saffir-Simpson U.S. Category	Central Pressure (mb)	Max Wind (kt)	Name
2010s						
2010	None					
2011	Aug	NC, 1	1	952	75	Irene
2012	Aug	LA, 1	1	966	70	Isaac
2012	Oct	* NY, 1	1	942	65	Sandy
2013	None					
2014	Jul	NC, 2	2	973	85	Arthur
2015	None					
2016	Sep	FL, NW1	1	981	70	Hermine
2016	Oct	* FL, NE2; GA, 1; SC, 1; NC, 1	2	963	85	Matthew
2017	Aug	TX,C4	4	937	115	Harvey
2017	Sep	FL, SW4,SE 1	4	931	115	Irma
2017	Oct	LA 1, MS 1	1	983	65	Nate
2018	Sep	NC, 1	1	956	80	Florence
2018	Oct	FL, NW5; I-GA, 2	5	919	140	Michael
2019	Jul	LA, 1	1	993	65	Barry
2019	Sep	NC, 2	2	956	85	Dorian
2020s						
2020	Jul	TX, S1	1	973	80	Hanna
2020	Aug	NC, 1; SC, 1	1	986	80	Isaias
2020	Aug	LA, 4; TX, N1	4	939	130	Laura
2020	Sep	AL, 2; FL, NW2	2	965	95	Sally
2020	Oct	LA,2	2	970	85	Delta
2020	Oct	LA,3; MS, 2; I-AL, 1	3	970	100	Zeta
2021	Aug	LA,4	4	931	130	Ida
2021	Sep	TX,N1	1	991	65	Nicholas
2022	Sep	FL, SW4; I-FL, SE1;FL, NE1; SC, 1	4	941	130	Ian

https://www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html

Tree mortality from forest pests and pathogens emit an average of 12.8 to 20.3 MMT of forest CO_2 per year



Harris et al. 2016, *Carbon Balance and Management,* DOI 10.1186/s13021-016-0066-5



Fei et al. 2019, *Proceedings of the National Academy of Science,* DOI 10.1073/pnas.1820601116

Forests emit carbon dioxide when they are disturbed.

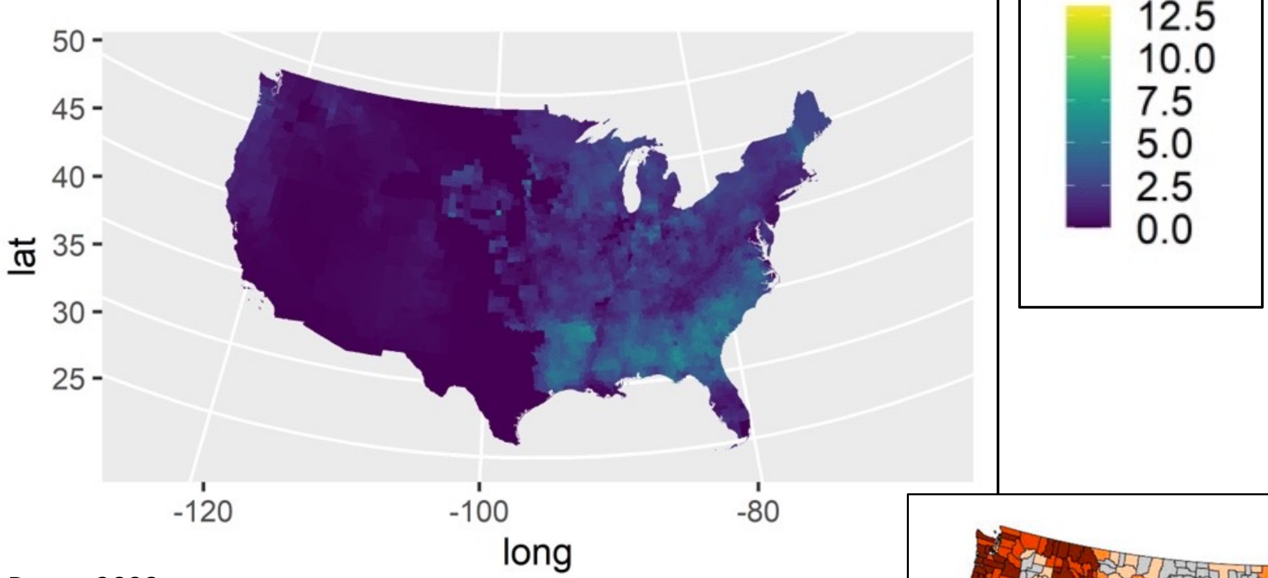
@CharlVera, Pixabay

@Matt Pardue, Wikimedia Commons

@K Dodd, Wikimedia Commons

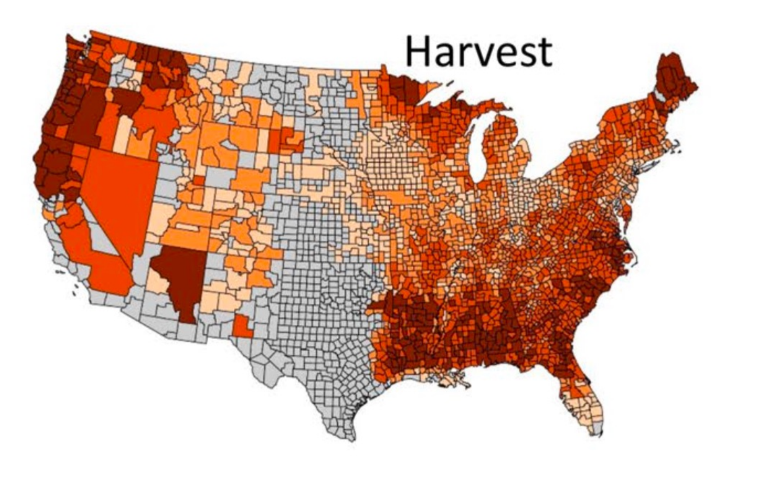
Unplanned disturbances

Forests emit carbon dioxide when they are disturbed



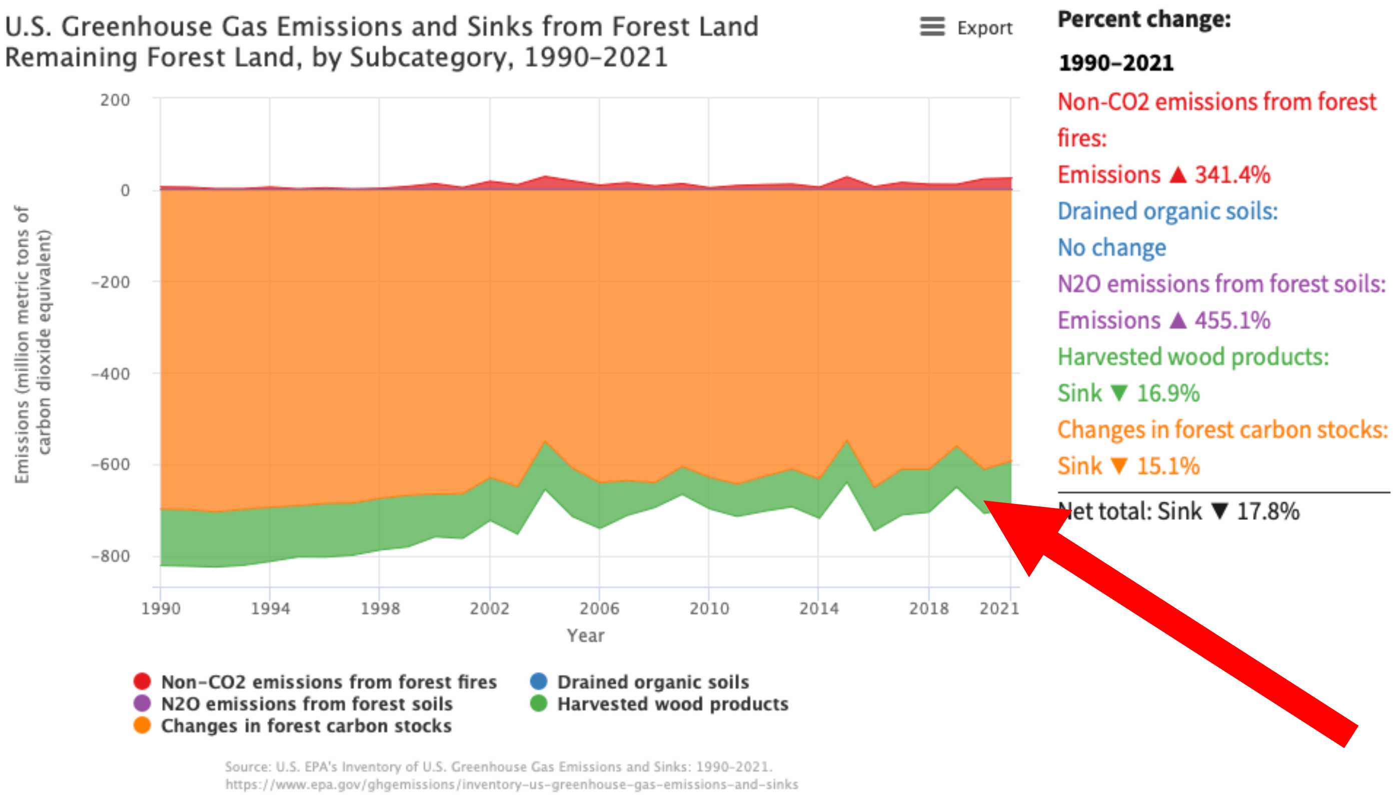
Ducey 2023

Percent annual forest area harvested



Harris et al. 2016, *Carbon Balance and Management*, DOI 10.1186/s13021-016-0066-5

But timber harvesting is estimated to be a net carbon sink because estimated annual carbon storage in wood products (446 MMT CO_2e) is greater than harvesting emissions (341 MMT CO_2e).



https://www.epa.gov/ghgreporting

US EPA. 2021. US Greenhouse Gas Reporting Program

Carbon & Climate-Smart Forestry

Carbon & Climate-Smart Forestry

forests MDPI

Article

By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry

Gert-Jan Nabuurs [1,*], Philippe Delacote [2], David Ellison [3], Marc Hanewinkel [4], Lauri Hetemäki [5], Marcus Lindner [5]

". . . the concept of "Climate Smart Forestry" (CSF) which we see as a more specific (climate-oriented) form of the Sustainable Forest Management paradigm. The idea behind CSF is that it considers the whole value chain from forest to wood products and energy, and illustrates that a wide range of measures can be applied to provide positive incentives for more firmly integrating climate objectives into the forest and forest sector framework. CSF is more than just storing carbon in forest ecosystems; it builds upon three main objectives;

(i) reducing and/or removing greenhouse gas emissions;
(ii) adapting and building forest resilience to climate change; and
(iii) sustainably increasing forest productivity and incomes. "

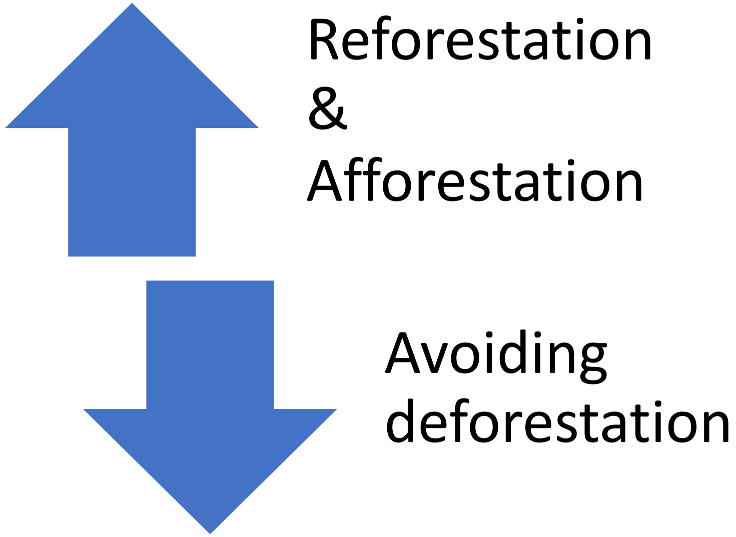
Forestry for reducing or removing greenhouse gas emission

Forests are highly-evolved, sophisticated 'direct air capture' facilities

Forestry for reducing or removing greenhouse gas emission

1. Increase the total amount of forestland
2. Increase forest carbon dioxide removal efficiency
3. Increase durability of forest carbon storage

Increase the total area of forest



Increase the total area of forest

Reforestation & Afforestation

Building new direct air capture facilities

Avoiding deforestation

Decommissioning existing direct air capture facilities

Reforestation & Afforestation

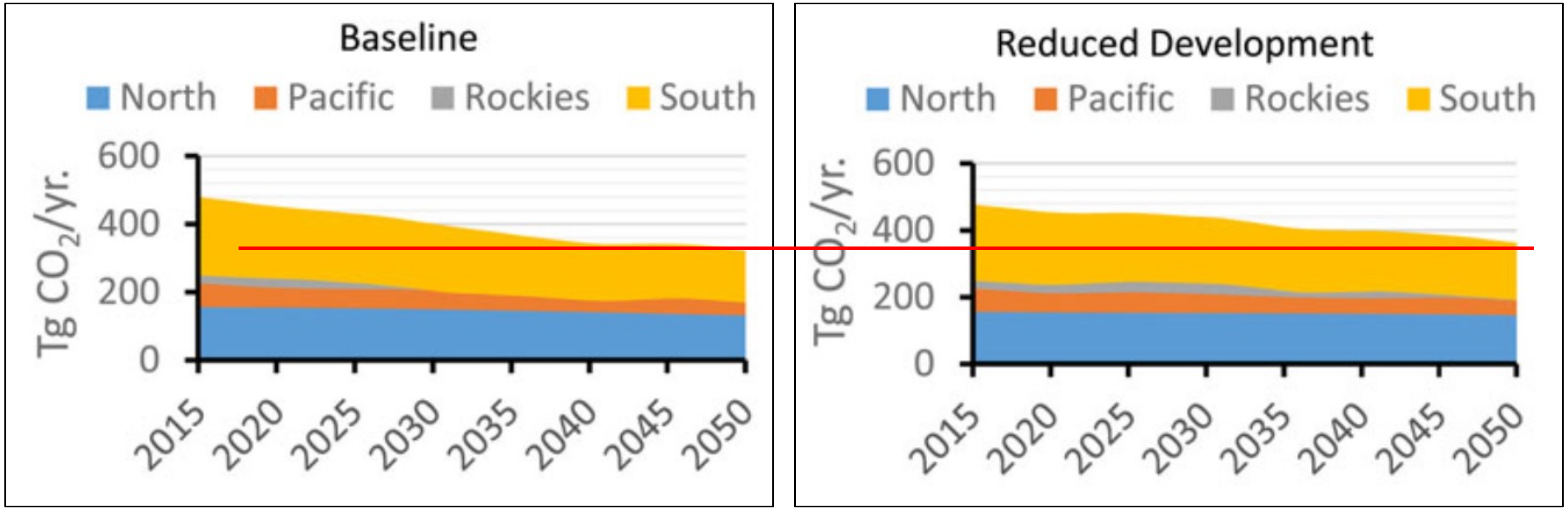
Planting trees is highly likely to increase total forestland carbon storage for the United States

Study	Reforestation & Afforestation Considerations	Area (Mha)	Mitigation Potential (MMT CO_2 per year)	Cost	Key Regions of Opportunity
Cook-Patton et al. 2020	Restoring tree cover in former forestland	51.6	314.2	~ 50% at < $20 tCO2 -1	Southeast
Fargione et al. 2018	Reforesting former forestland that is not currently wetland, active cropland, or livestock pastureland.	62.9	306.6	~ 80% < $50 USD Mg CO2e-1	Northeast and south central
Haight et al. 2020	Incentivizing private landowners in the eastern US to plant trees and planting trees in federal forests in the west.	15.1	107	6.5 Billion	South
Wear and Coulston 2015	Incentivizing private landowners in the eastern US to retire croplands and plant trees and planting trees in federal forests in the west.	7.73	27.6	--	South and Pacific Northwest
Zhang et al. 2023	Planting pine trees in the southeastern United States for pineland restoration	2.1	71.14	$1.22 per tonne	Southeast

Avoided forest conversion

Future projections estimate that avoiding forest conversion could protect ~39 MMT CO_2e

Source	Forest C Protection (MMT CO_2 per year)	Key Regions of Opportunity
Fargione et al. 2018	38	Southern, Pacific Northwest
Haight et al. 2020	39	Rocky Mountains

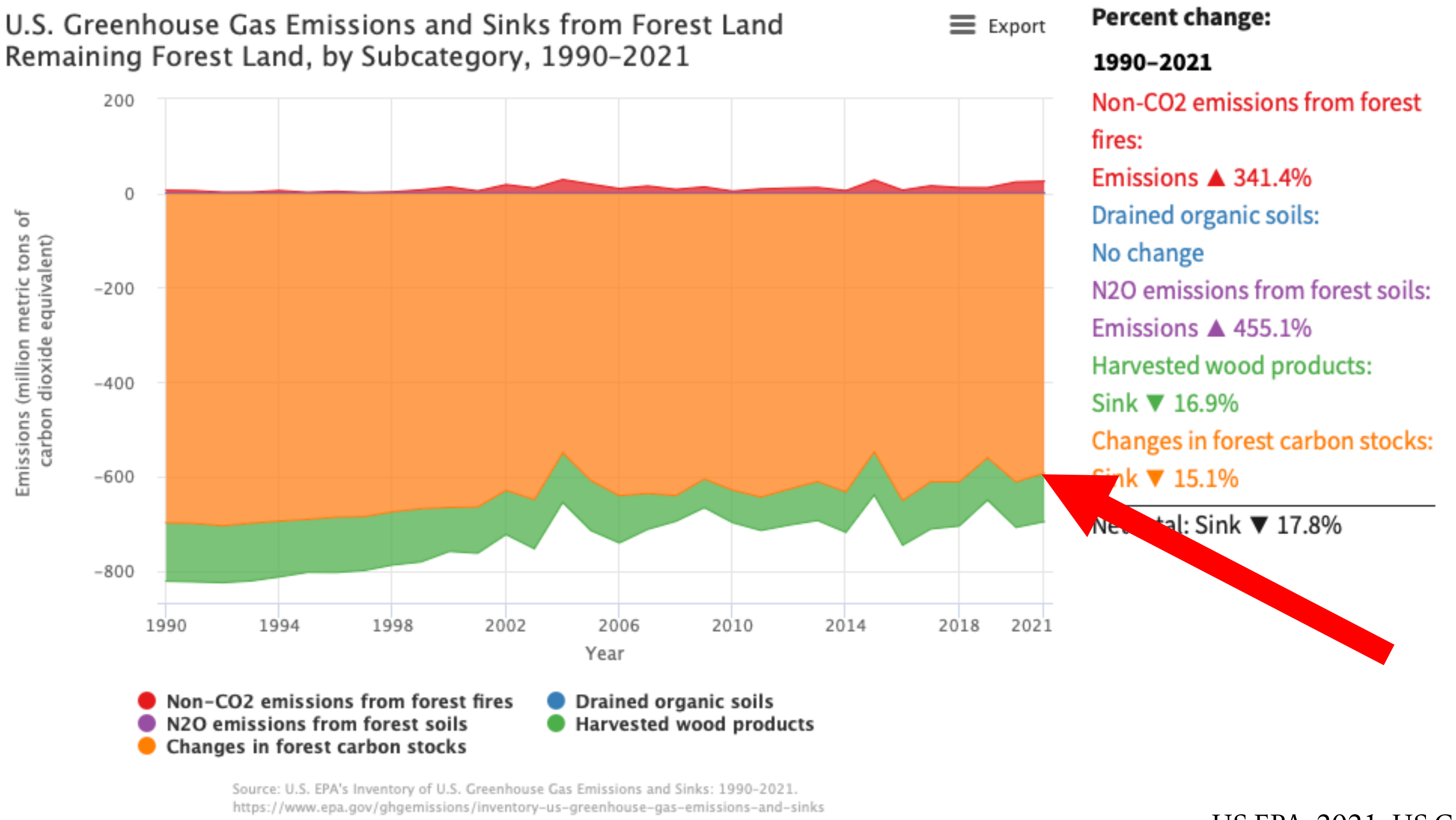


Haight et al. 2020, *Agricultural and Resource Economics Review,* DOI 10.1017/age.2019.20

Forestry for reducing or removing greenhouse gas emission

1. Increase the total amount of forest
2. Increase forest carbon dioxide removal efficiency

In 2021, US forest captured ~ 593 MMT CO_2e



Increase forest carbon dioxide removal efficiency

Increasing # trees (stocking density) within existing forestlands

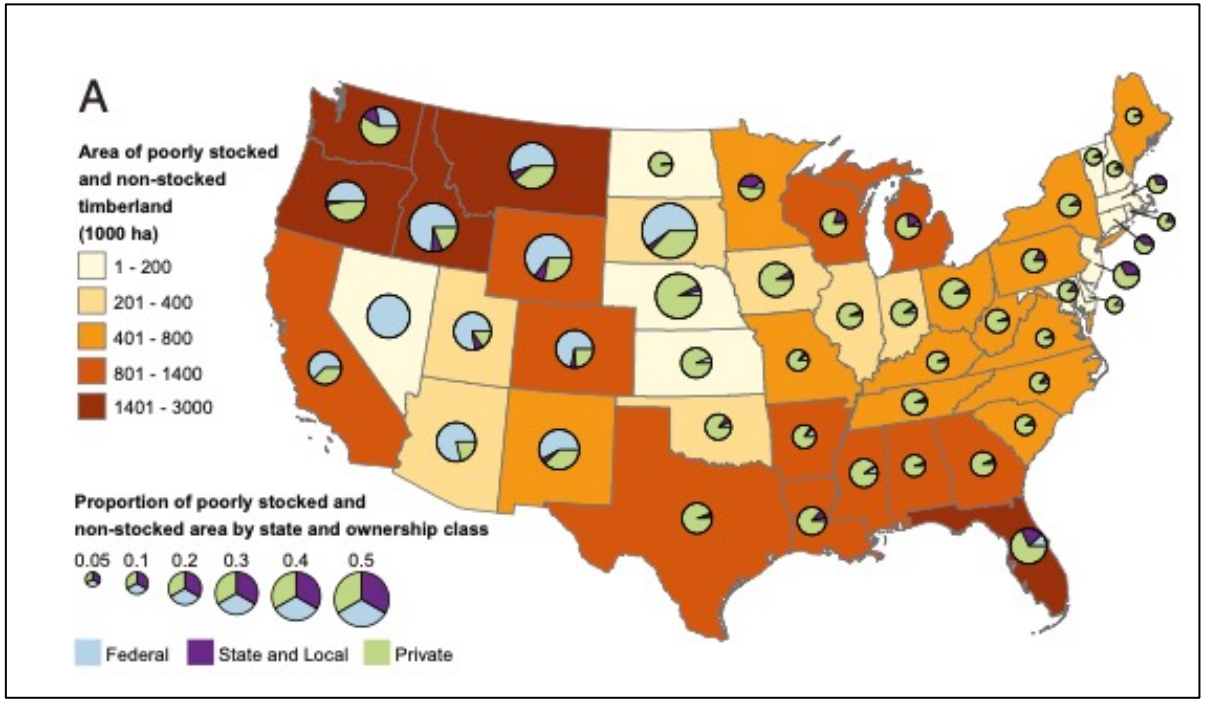
Increasing the number of fans and filters at an existing DAC facilities

"Improved Forest Management" to promote tree health

Maintenance of broken fans and filters

Increasing # trees (stocking density) within existing forestlands

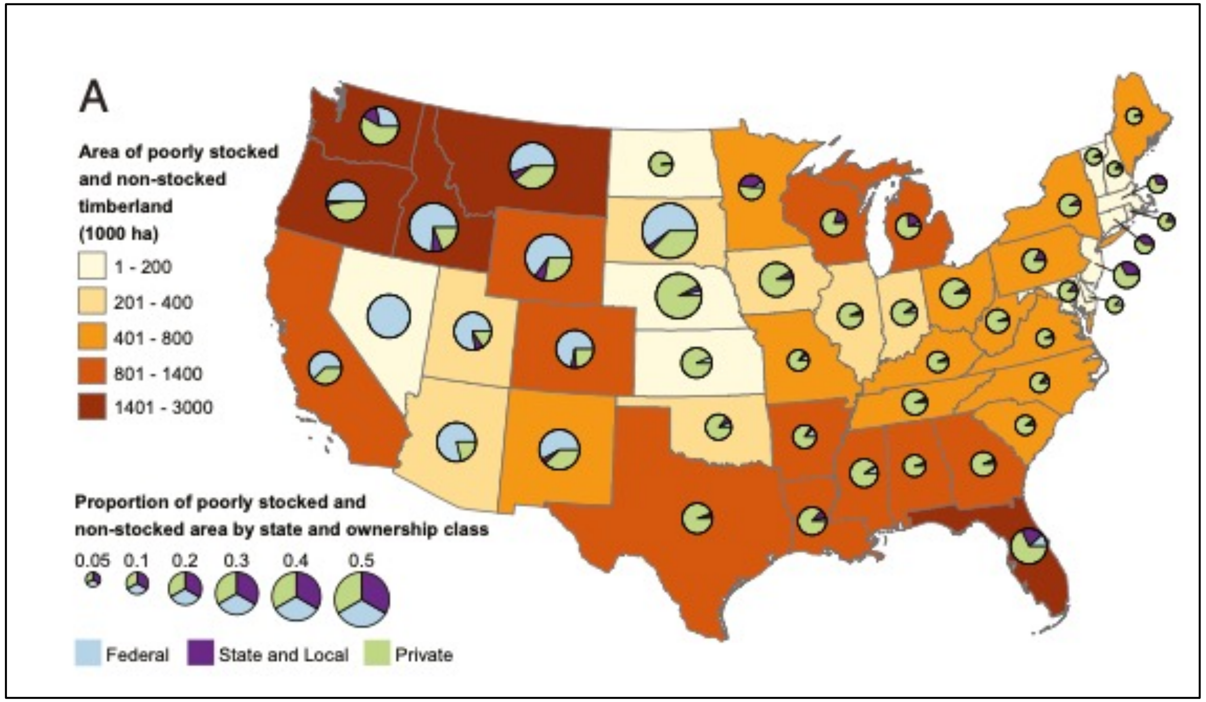
Understocked US timberlands sequester 20% less carbon dioxide and store 30% less carbon in trees than fully stocked forests

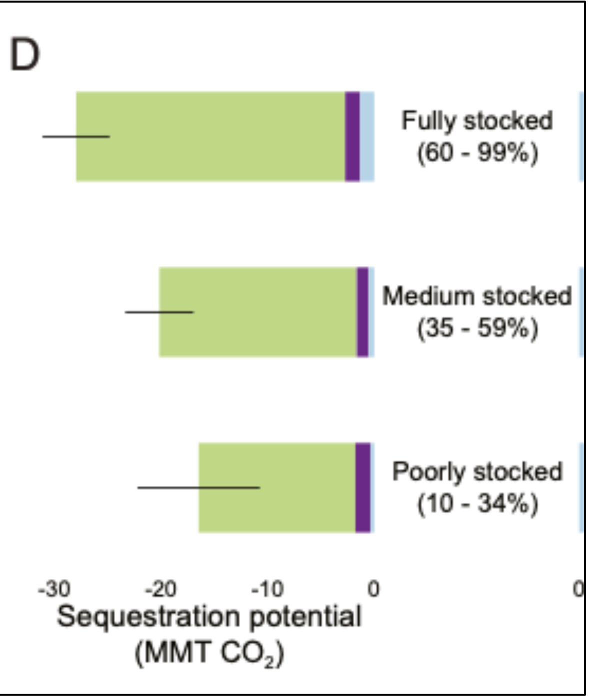


Domke et al. 2020, *Proceedings of the National Academy of Science,* DOI 10.1073/pnas.2010840117

Increasing # trees (stocking density) within existing forestlands

Fully stocking understocked timberland could increase forest CO_2 removals by 20% (187.7 ± 9.1 MMT CO_2) per year





Domke et al. 2020, *Proceedings of the National Academy of Science*, DOI 10.1073/pnas.2010840117

What is IFM?

"Improved Forest Management"

Received: 1 April 2021 | Accepted: 20 June 2021
DOI: 10.1002/2688-8319.12090

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

NATURE-BASED SOLUTIONS FOR A CHANGING WORLD

Review

Improved forest management as a natural climate solution: A review

Lilli Kaarakka[1,2] | Meredith Cornett[3] | Grant Domke[4] | Todd Ontl[5] |
Laura E. Dee[2]

TABLE 4 Definition of improved forest management proposed by this synthesis

	Proposed definition	Silvicultural management practices
Improved forest management (IFM)	IFM encompasses a range of silvicultural management actions that incorporate above- and below-ground biomass C components, as well soil C stocks.	Extended rotations Thinning for stand improvement and fuel management Promoting uneven-aged forest management (including partial harvesting) Facilitating stand re-establishment/regeneration and seedling survival Avoiding logging damage to remaining trees Species selection: retaining native species, and if possible, diversifying species in stand Minimizing soil disturbance and extensive soil damage: compaction, mixing and displacement Retain coarse woody debris (stumps, downed trees, snags) in a stand

Kaarakka et al. 2021, *Ecological Solutions and Evidence,* DOI 10.1002/2688-8319.12090

What is IFM?

"Improved Forest Management"

Received: 1 April 2021 | Accepted: 20 June 2021
DOI: 10.1002/2688-8319.12090

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

NATURE-BASED SOLUTIONS FOR A CHANGING WORLD

Review

Improved forest management as a natural climate solution: A review

Lilli Kaarakka[1,2] | Meredith Cornett[3] | Grant Domke[4] | Todd Ontl[5] |
Laura E. Dee[2]

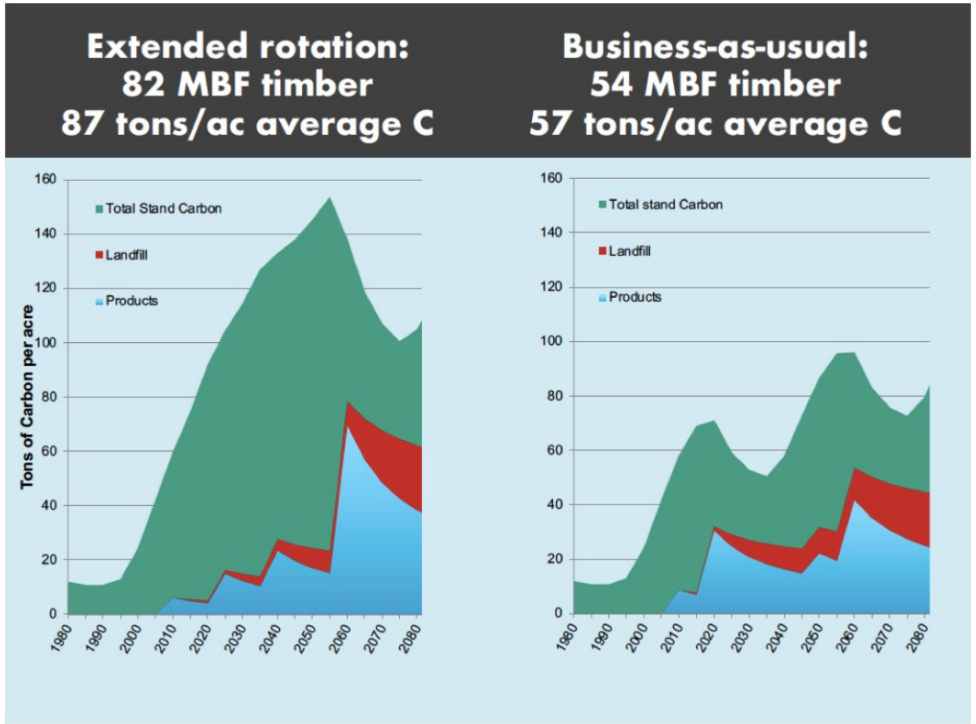
TABLE 4 Definition of improved forest management proposed by this synthesis

	Proposed definition	Silvicultural management practices
Improved forest management (IFM)	IFM encompasses a range of silvicultural management actions that incorporate above- and below-ground biomass C components, as well soil C stocks.	Extended rotations
		Thinning for stand improvement and fuel management
		Promoting uneven-aged forest management (including partial harvesting)
		Facilitating stand re-establishment/regeneration and seedling survival
		Avoiding logging damage to remaining trees
		Species selection: retaining native species, and if possible, diversifying species in stand
		Minimizing soil disturbance and extensive soil damage: compaction, mixing and displacement
		Retain coarse woody debris (stumps, downed trees, snags) in a stand

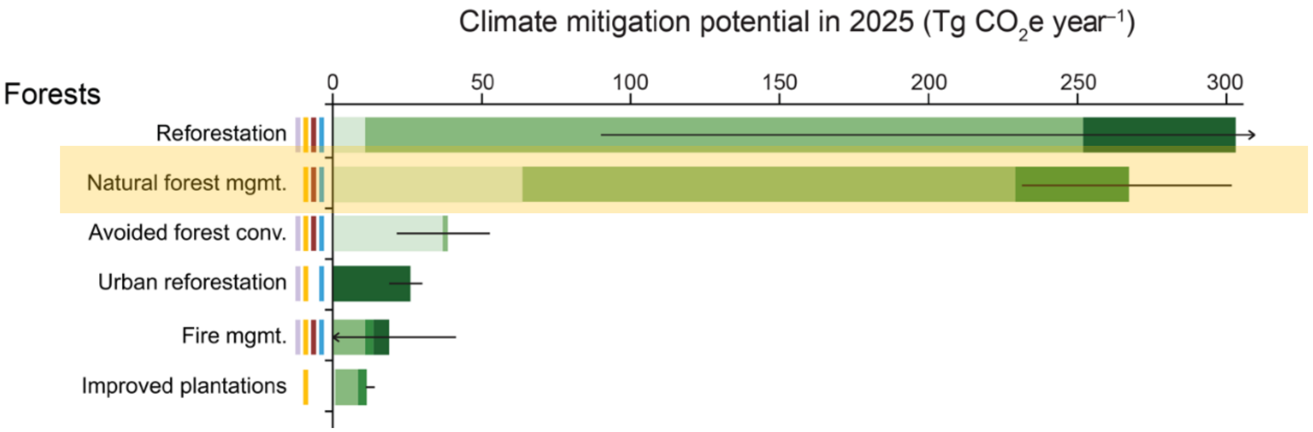
Kaarakka et al. 2021, *Ecological Solutions and Evidence,* DOI 10.1002/2688-8319.12090

"Improved Forest Management"

Extended rotations of private, commercial forestland estimated to avoid 267 MMT forest CO_2 emissions per year



Zuckerman 2021, *Northwest Natural Resource Group*



Fargione et al. 2018, *Scientific Advances*, DOI 10.1126/sciadv.aat1869

"Improved Forest Management"

Limited empirical or modeling work on the direct effects of IFM on forest carbon stocks and sequestration at regional or national scales

Received: 1 April 2021 | Accepted: 20 June 2021
DOI: 10.1002/2688-8319.12090

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

NATURE-BASED SOLUTIONS FOR A CHANGING WORLD

Review

Improved forest management as a natural climate solution: A review

Lilli Kaarakka[1,2] | Meredith Cornett[3] | Grant Domke[4] | Todd Ontl[5] | Laura E. Dee[2]

TABLE 4 Definition of improved forest management proposed by this synthesis

	Proposed definition	Silvicultural management practices
Improved forest management (IFM)	IFM encompasses a range of silvicultural management actions that incorporate above- and below-ground biomass C components, as well soil C stocks.	Extended rotations
		Thinning for stand improvement and fuel management
		Promoting uneven-aged forest management (including partial harvesting)
		Facilitating stand re-establishment/regeneration and seedling survival
		Avoiding logging damage to remaining trees
		Species selection: retaining native species, and if possible, diversifying species in stand
		Minimizing soil disturbance and extensive soil damage: compaction, mixing and displacement
		Retain coarse woody debris (stumps, downed trees, snags) in a stand

Kaarakka et al. 2021, *Ecological Solutions and Evidence*, DOI 10.1002/2688-8319.12090

"Improved Forest Management"

Ecological theory and local studies support IFM as a tool

International Conservation News

Reduced-Impact Logging as a Carbon-Offset Method

Conservation Biology
Volume 7, No. 4, December 1993

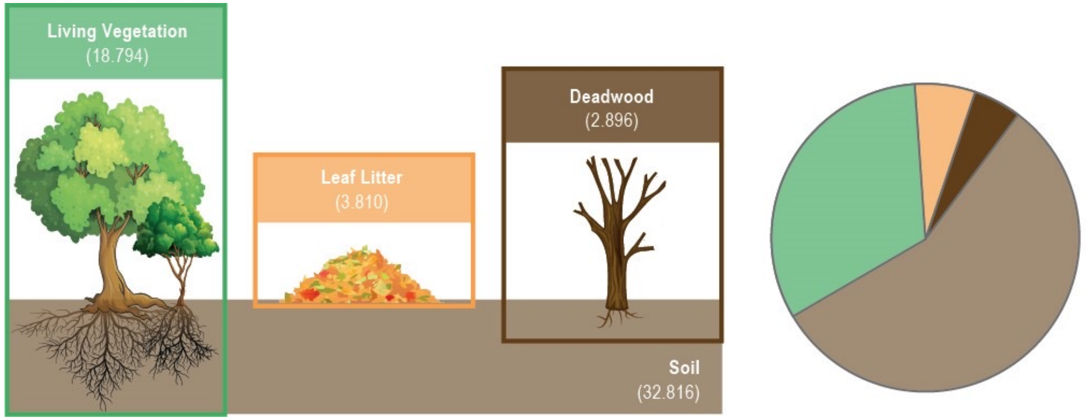
Avoiding logging damage
(aka "reduced impact logging")

Logging Damage to White Oak Trees

"Improved Forest Management"

Ecological theory and local studies support IFM as a tool

Avoiding soil disturbance



UNIVERSITY of WISCONSIN–MADISON

News

Explore Topics | Campus News | UW in the News | For Media

Muddy forests, shorter winters present challenges for loggers

December 22, 2014 | By David Tenenbaum

A new study finds that the period of frozen ground has declined by an average of two or three weeks since 1948. Logging trucks have a harder time accessing forests with wet, unfrozen soil – and can leave their marks along the way.

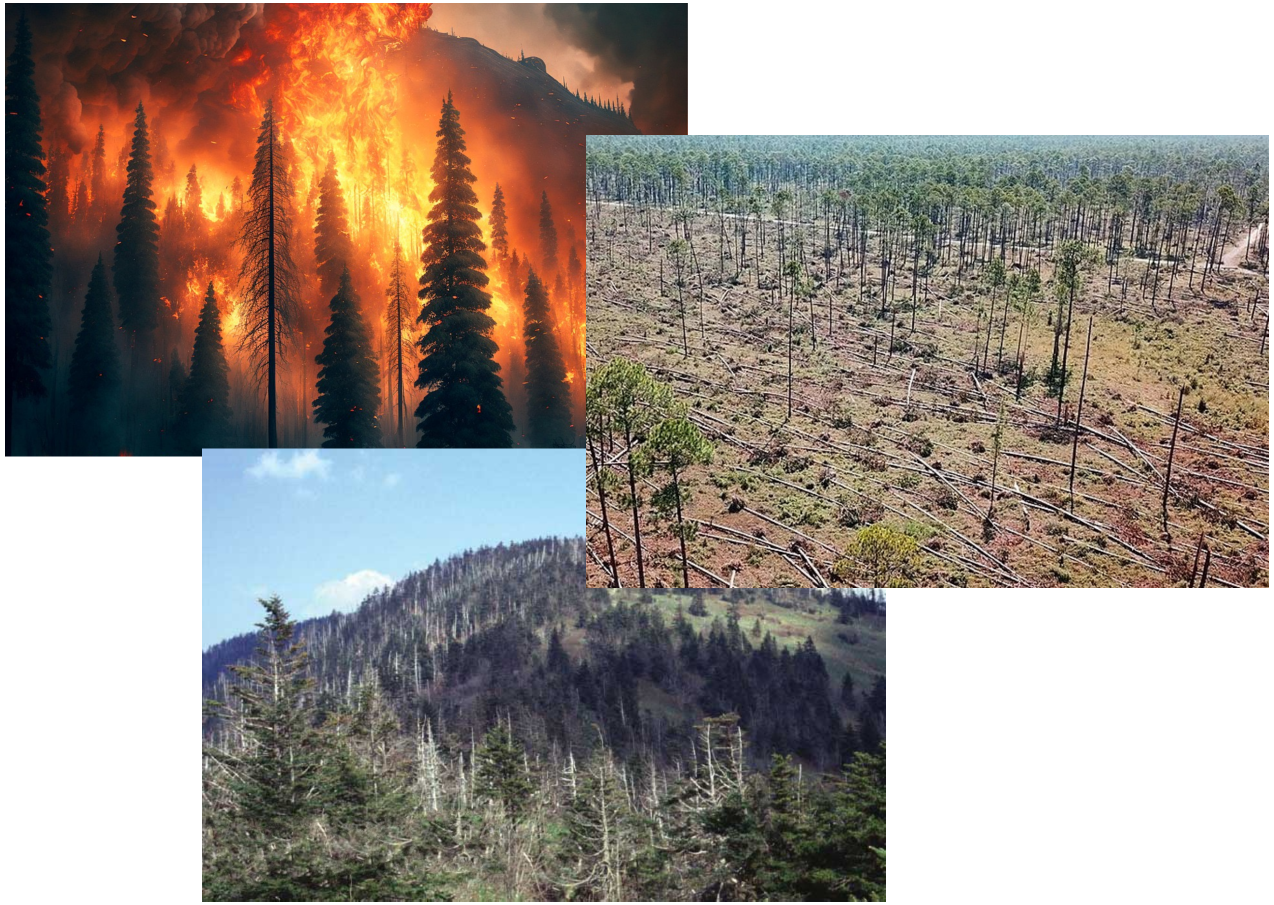
Photo: Wisconsin DNR

https://news.wisc.edu/muddy-forests-shorter-winters-present-challenges-for-loggers/

Forestry for reducing or removing greenhouse gas emission

1. Increase the total amount of forest
2. Increase forest carbon dioxide removal efficiency
3. Increase durability of forest carbon storage

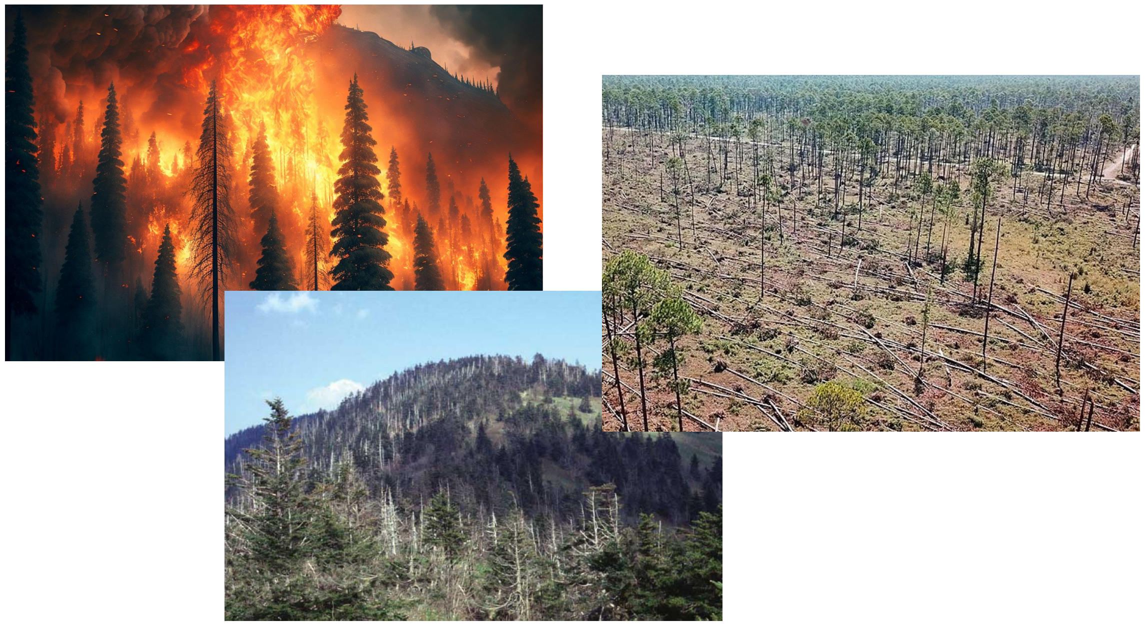
Forests emit carbon dioxide when they are disturbed.



Unplanned disturbances

Planned disturbances

Forests emit carbon dioxide when they are disturbed.

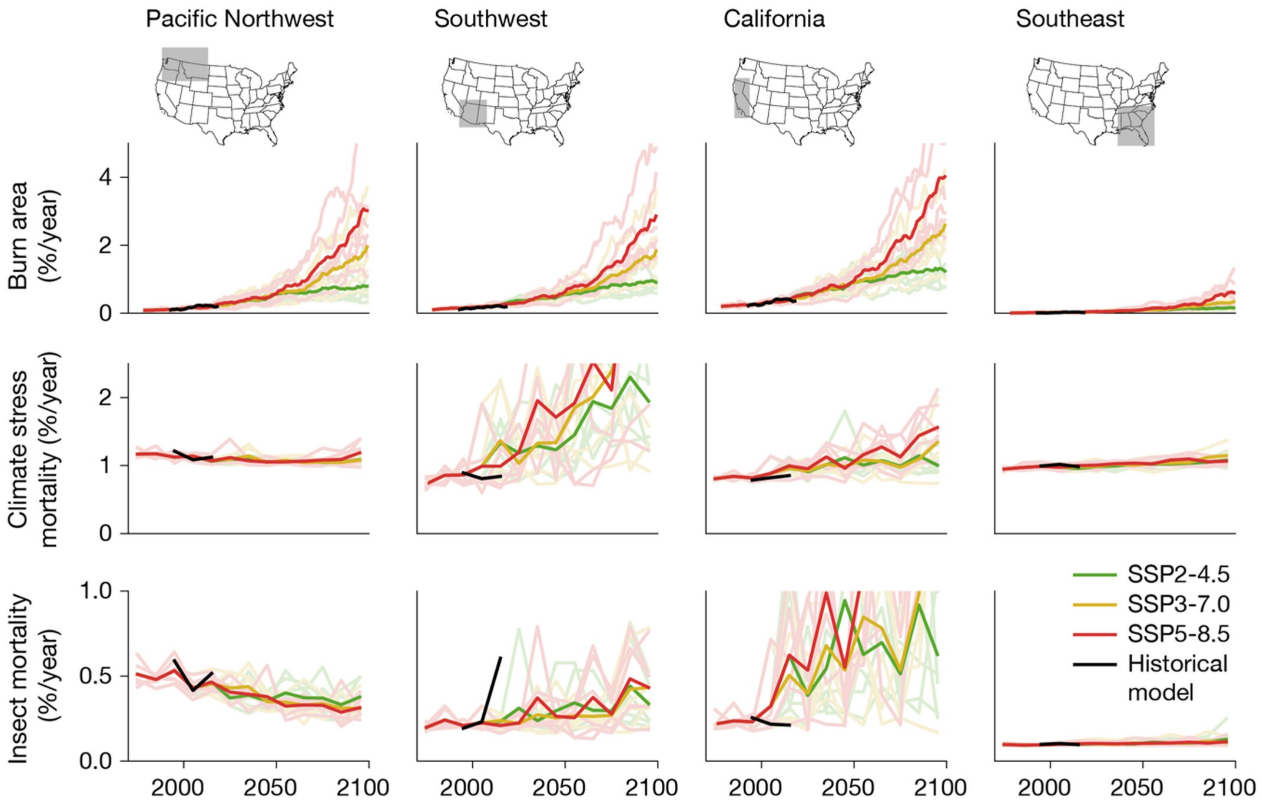


Unplanned disturbances =
Less direct control

- Impossible to predict over space and time;
- impact of disturbance on forest varies locally;

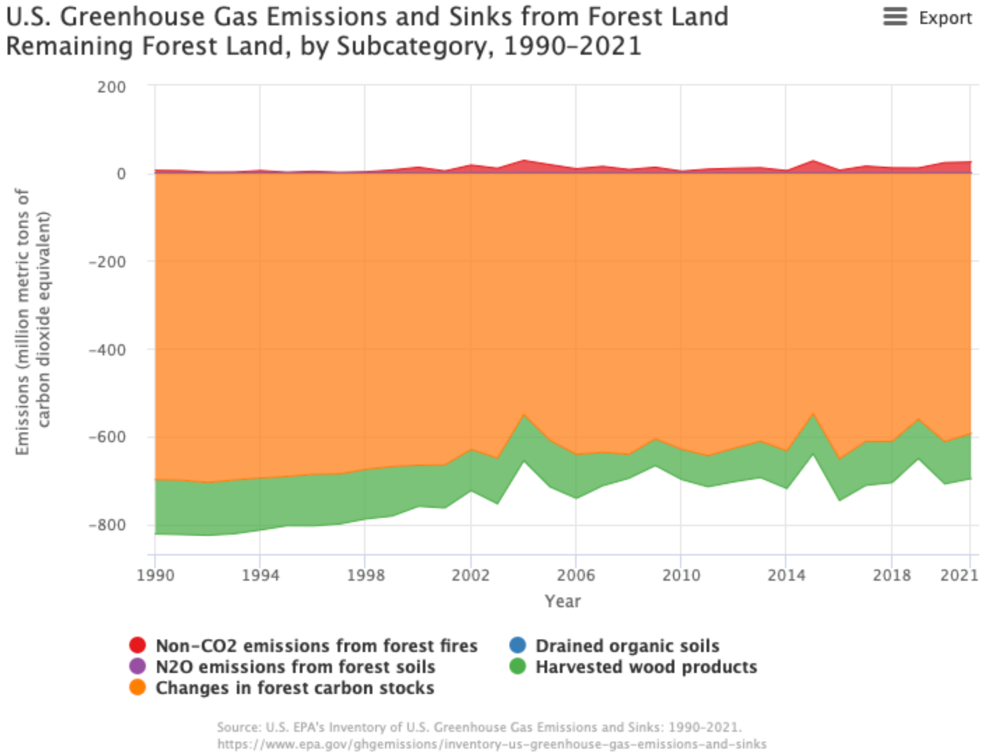
Planned disturbances =
More control

Unplanned disturbances are projected to increase with increasing atmospheric CO_2



Anderegg et al. 2022, *Ecology Letters,* DOI 10.1111/ele.14018

Forests are part of our carbon accounting budget –whether we choose to manage or not



Percent change:

1990–2021

Non-CO2 emissions from forest fires:
Emissions ▲ 341.4%

Drained organic soils:
No change

N2O emissions from forest soils:
Emissions ▲ 455.1%

Harvested wood products:
Sink ▼ 16.9%

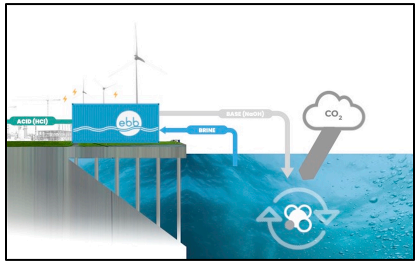
Changes in forest carbon stocks:
Sink ▼ 15.1%

Net total: Sink ▼ 17.8%

US EPA. 2021. US Greenhouse Gas Reporting Program

https://www.epa.gov/ghgreporting

ALL climate mitigation facilities can be disturbed by hurricanes and wildfires



Analysis

Weather tracker: Hurricane Idalia leaves trail of damage in Florida

Matt Williams for MetDesk

Category 3 storm causes extensive flooding in south-east US, while heavy rain and winds also hit France and Italy

Damaged buildings in the town of Horseshoe Beach, Florida. Photograph: Cristóbal Herrera/EPA

In case of hurricane, apply Enphase, tighten bolts and mind your wind codes!

FEMA's recommendations for solar system hurricane preparedness focused on structural engineering, installation competence, plus simply tightening the bolts regularly, along with microinverters to mitigate individual panel damage.

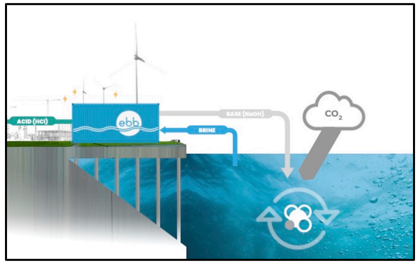
NOVEMBER 29, 2018 JOHN FITZGERALD WEAVER

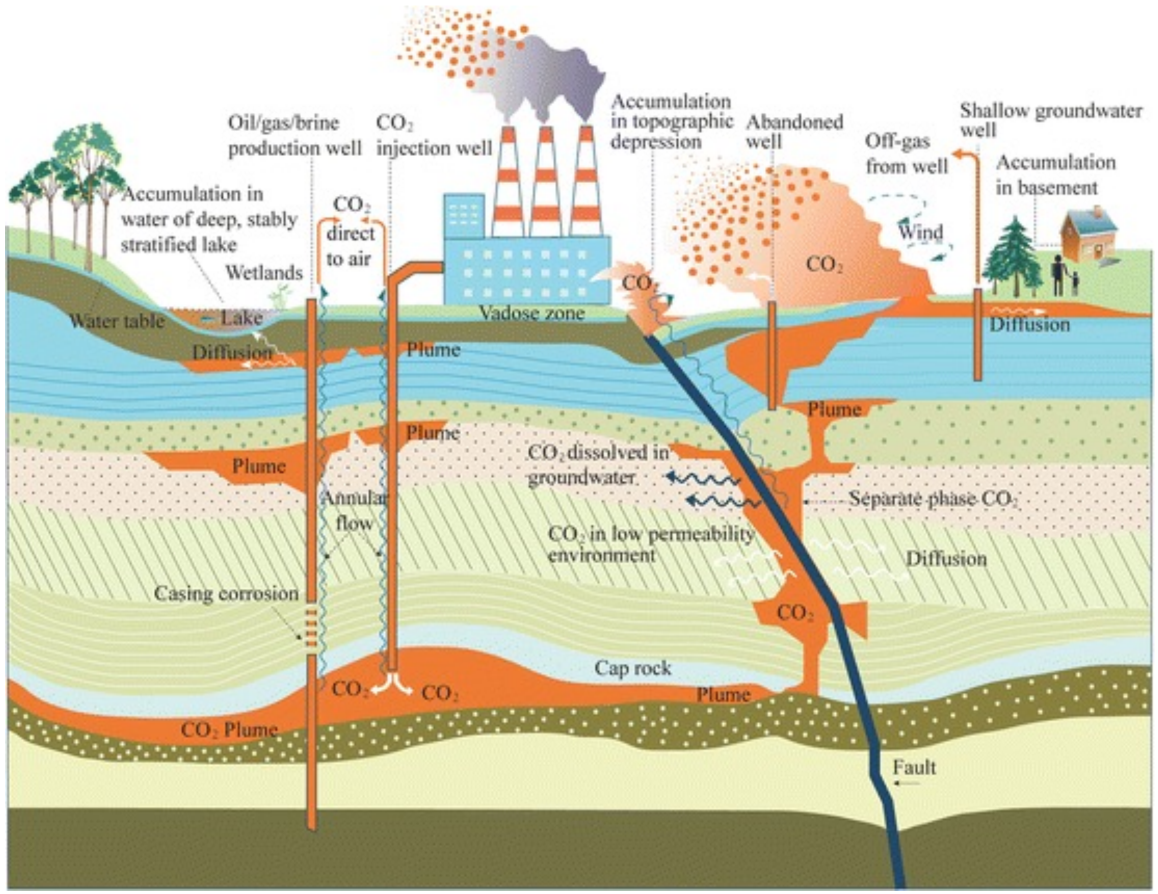
DISASTER RECOVERY | OPTIMIZERS & INVERTERS | RACKING | RESIDENTIAL PV | UNITED STATES

FEMA

Kilo Fire. Photo credit, Los Angeles County Fire Department.

ALL carbon storage facilities can be 'leaky'





Li and Liu 2016, *Geological Carbon Sequestration*, DOI 10.1007/978-3-319-27019-7_13

Increase durability of forest carbon

Increase forest resilience to unplanned disturbances	Increase infrastructure resilience to unplanned disturbances.
Increase climate benefits harvested wood products	?

Increase forest resilience to unplanned disturbances

'Improved forest management' practices likely to increase forest resilience, but empirical data is local and limited

Received: 1 April 2021 | Accepted: 20 June 2021
DOI: 10.1002/2688-8319.12090
Ecological Solutions and Evidence
BRITISH ECOLOGICAL SOCIETY
NATURE-BASED SOLUTIONS FOR A CHANGING WORLD
Review

Improved forest management as a natural climate solution: A review

Lilli Kaarakka[1,2] | Meredith Cornett[3] | Grant Domke[4] | Todd Ontl[5] | Laura E. Dee[2]

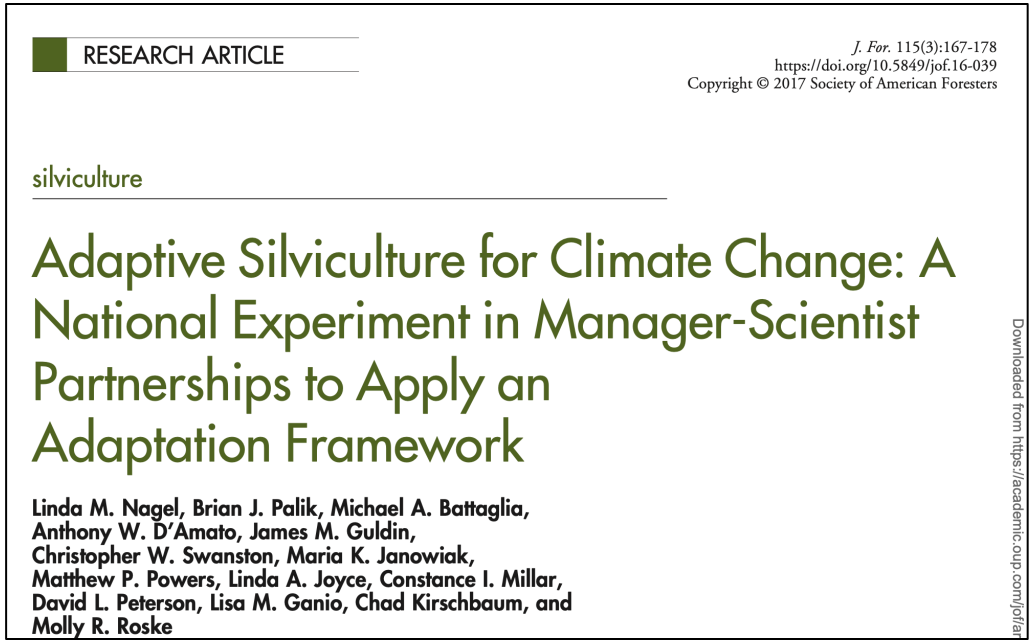
TABLE 4 Definition of improved forest management proposed by this synthesis

	Proposed definition	Silvicultural management practices
Improved forest management (IFM)	IFM encompasses a range of silvicultural management actions that incorporate above- and below-ground biomass C components, as well soil C stocks.	Extended rotations
		Thinning for stand improvement and fuel management
		Promoting uneven-aged forest management (including partial harvesting)
		Facilitating stand re-establishment/regeneration and seedling survival
		Avoiding logging damage to remaining trees
		Species selection: retaining native species, and if possible, diversifying species in stand
		Minimizing soil disturbance and extensive soil damage: compaction, mixing and displacement
		Retain coarse woody debris (stumps, downed trees, snags) in a stand

Kaarakka et al. 2021, *Ecological Solutions and Evidence,* DOI 10.1002/2688-8319.12090

Increase forest resilience to unplanned disturbances

. . . But data is coming . . .


RESEARCH ARTICLE

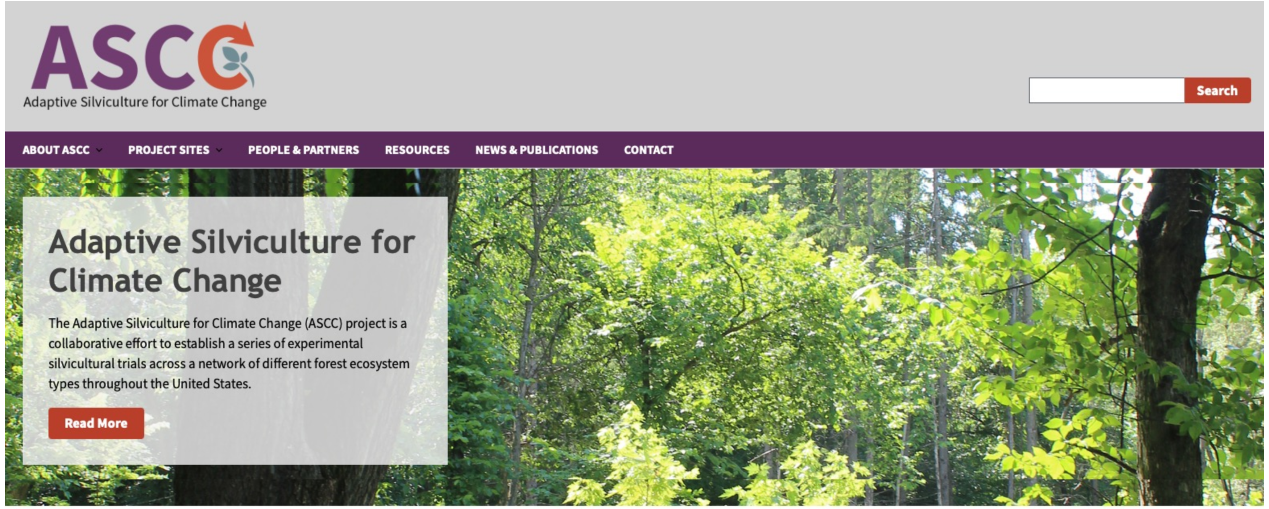
J. For. 115(3):167-178
https://doi.org/10.5849/jof.16-039
Copyright © 2017 Society of American Foresters

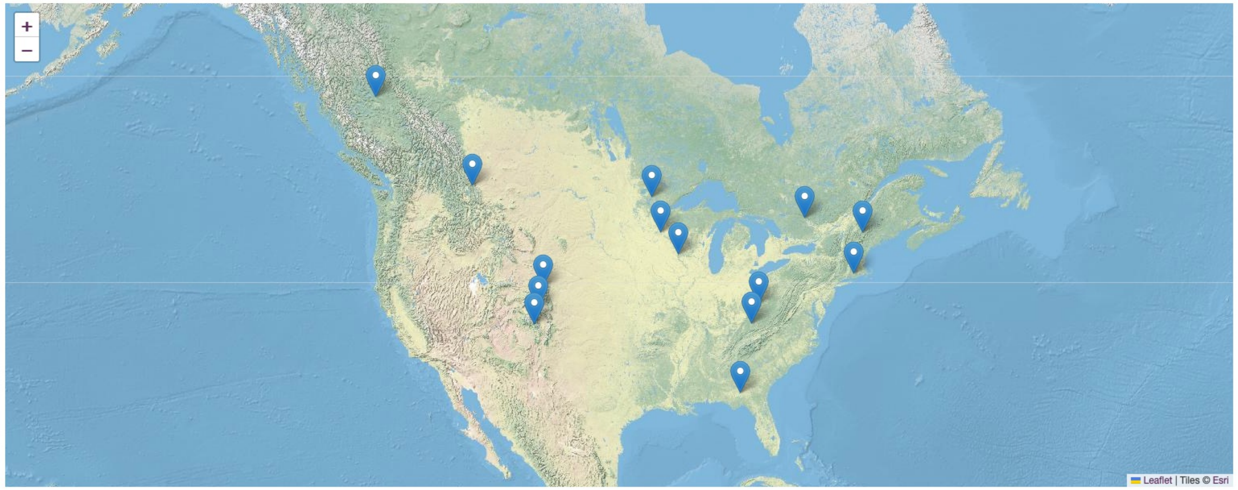
silviculture

Adaptive Silviculture for Climate Change: A National Experiment in Manager-Scientist Partnerships to Apply an Adaptation Framework

Linda M. Nagel, Brian J. Palik, Michael A. Battaglia, Anthony W. D'Amato, James M. Guldin, Christopher W. Swanston, Maria K. Janowiak, Matthew P. Powers, Linda A. Joyce, Constance I. Millar, David L. Peterson, Lisa M. Ganio, Chad Kirschbaum, and Molly R. Roske

Downloaded from https://academic.oup.com/jof/ar



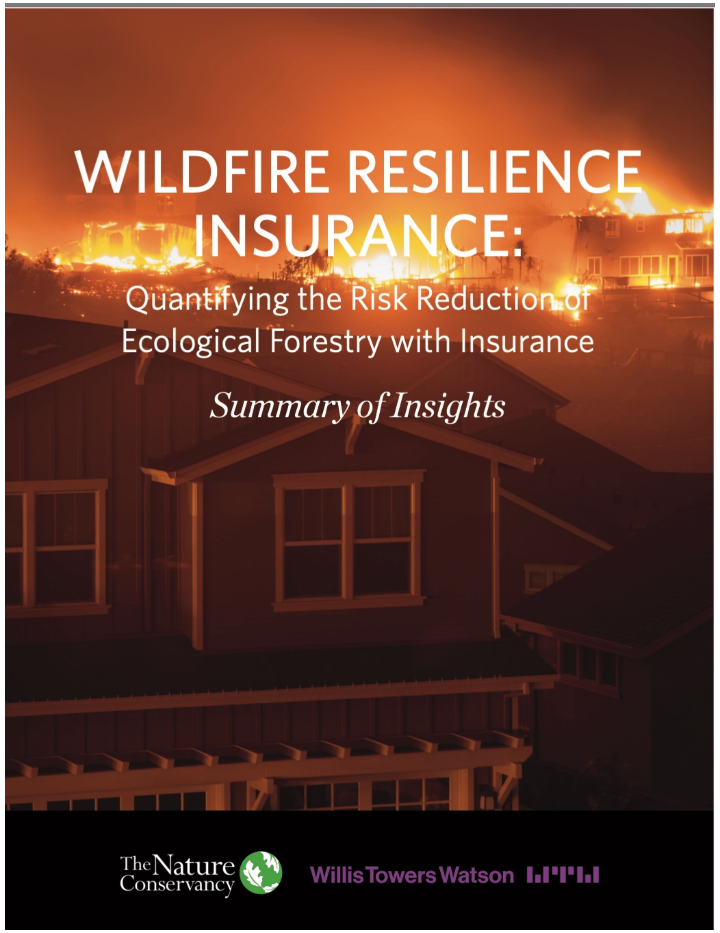


Increase forest resilience to unplanned disturbances

Managing for forest resilience to wildfire and pests and pathogens

Increase forest resilience to unplanned disturbances

Thinning overstocked forests can reduce wildfire impact

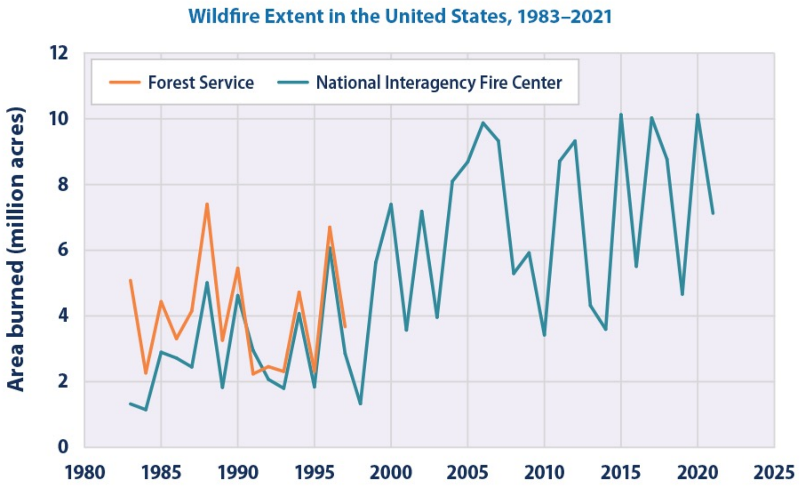


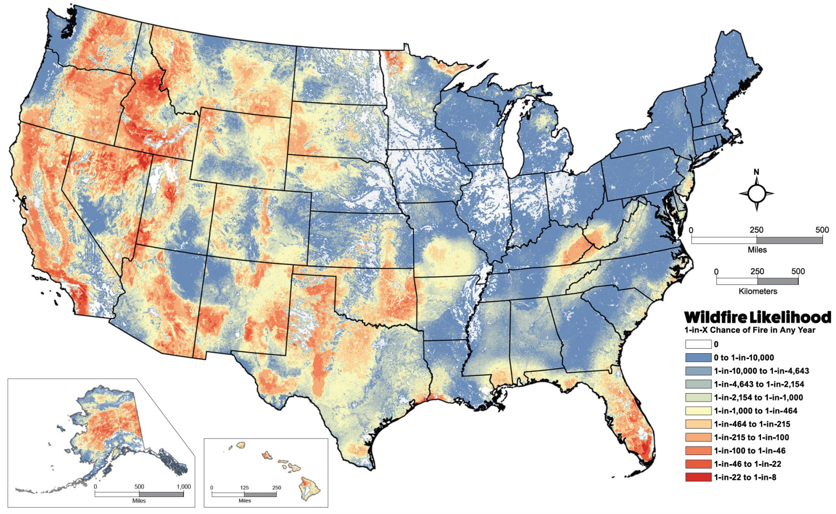
UNMANAGED FOREST Fire in an unmanaged ponderosa pine forest (where fires have been repeatedly suppressed): Overcrowding can make the forest less healthy and resilient. When such a forest burns, the fire can extend into the crowns, killing large swaths of trees. © Erica Sloniker / TNC

MANAGED FOREST Fire in a managed ponderosa pine forest (using controlled burns with or without mechanical thinning): A fire burns low through the understory, maintaining gaps between some trees that help prevent future large crown fires. © Erica Sloniker / TNC

Increase forest resilience to unplanned disturbances

But because we do not know when or where fire will occur, fire resilience treatments may opt to prioritize human and ecological communities…not carbon





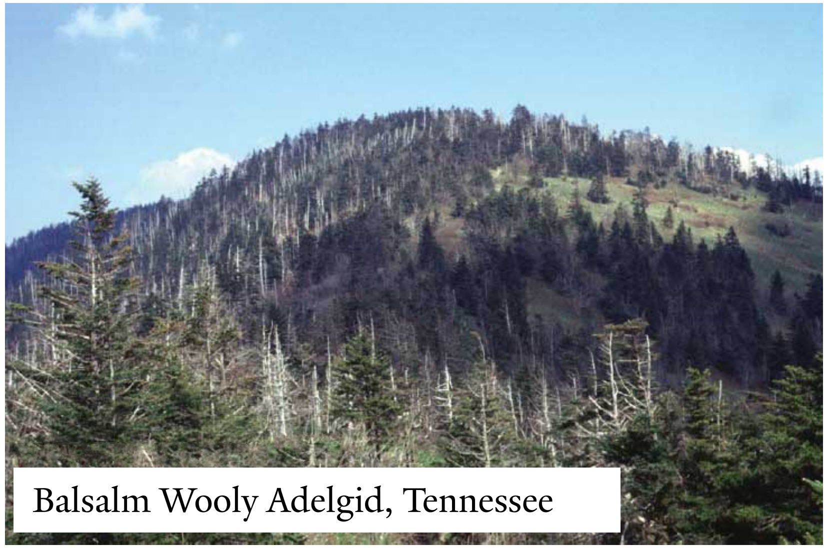
Lewis 2023.

Increase forest resilience to unplanned disturbances

Protecting forests from introduced pests and pathogens: the old

Laurel wilt disease, Georgia

© Kevin Potter



Balsalm Wooly Adelgid, Tennessee

© Wikimedia

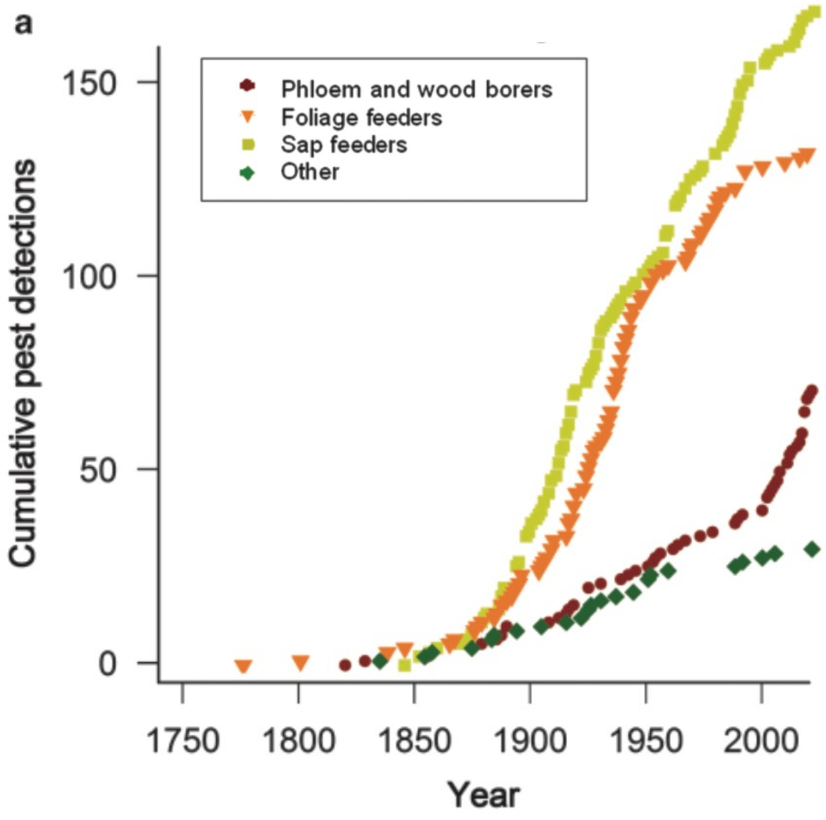
Mountain Pine Beetle, Colorado

Increase forest resilience to unplanned disturbances

Protecting forests from introduced pests and pathogens: the NEW

© Kevin Lynch

© Michigan Dept. of Nature Resources



Aukema et al. 2010, *BioScience*, DOI 10.1525/bio.2010.60.11.5

Increase forest resilience to unplanned disturbances

We need more robust policies to prevent accidental introduction of forest pests

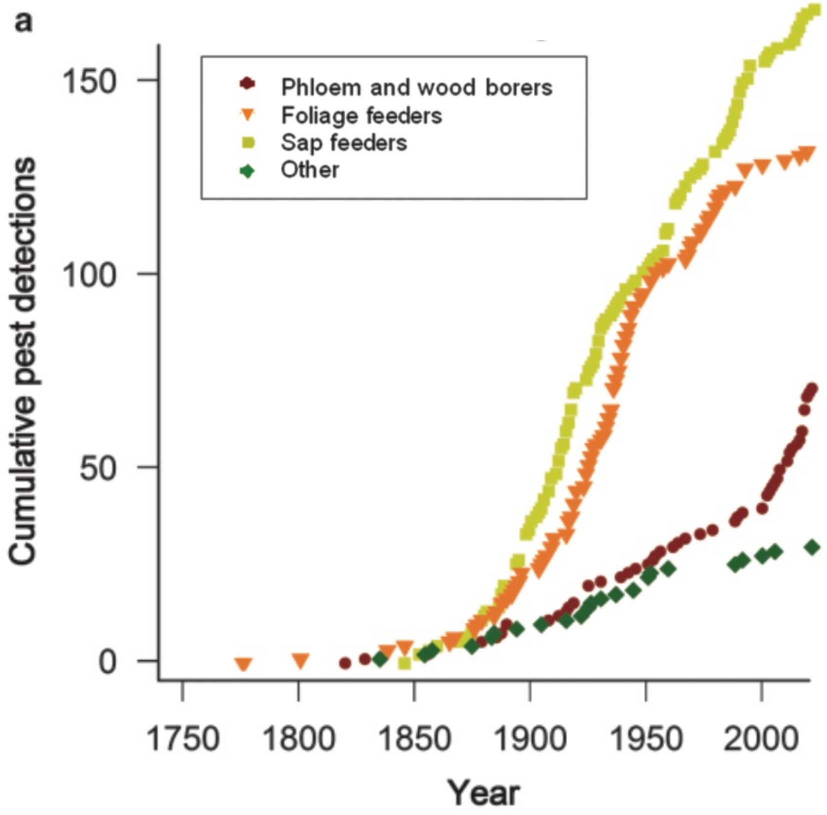
BIOLOGICAL REVIEWS

Cambridge Philosophical Society

Biol. Rev. (2020), **95**, pp. 1511–1534. 1511
doi: 10.1111/brv.12627

Scientists' warning on invasive alien species

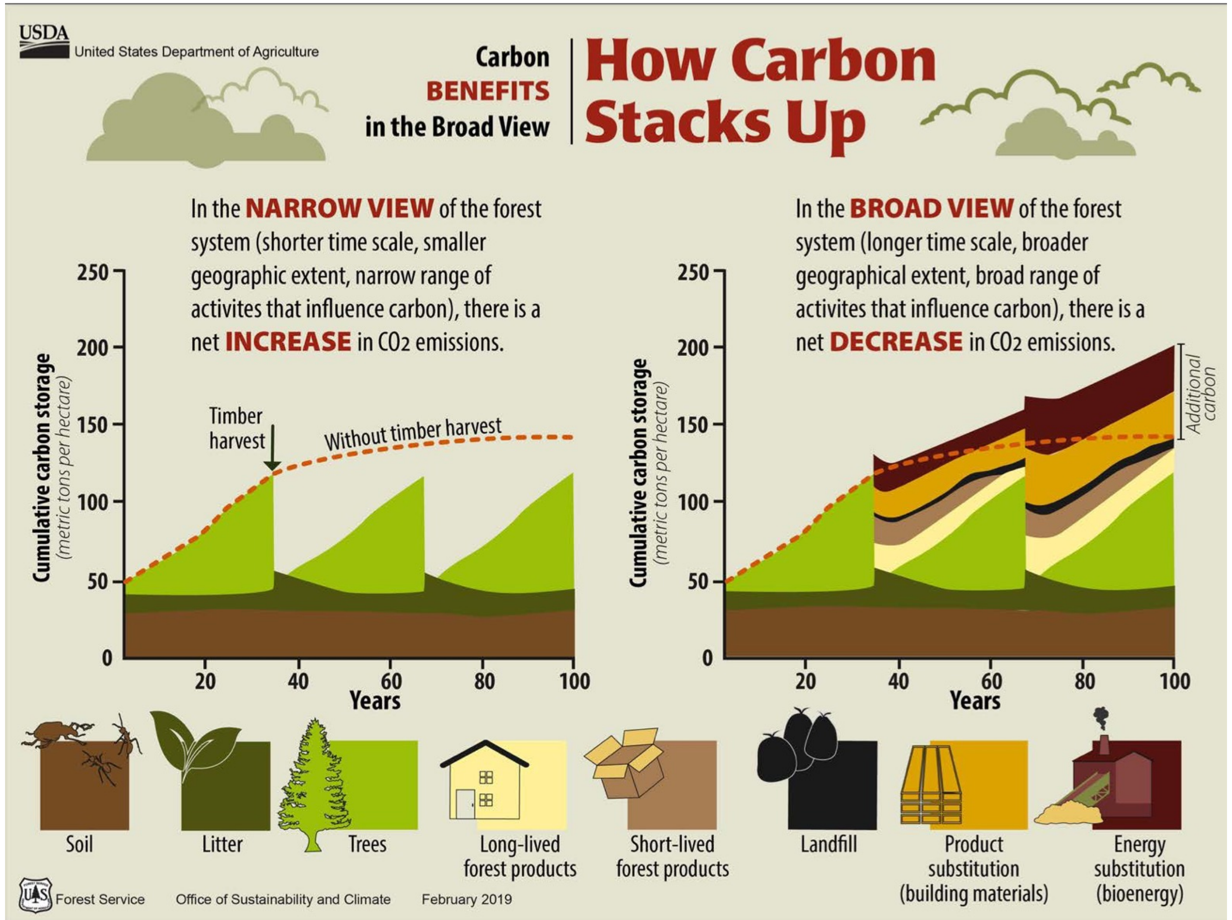
Petr Pyšek[1,2,3*], Philip E. Hulme[4], Dan Simberloff[5], Sven Bacher[6], Tim M. Blackburn[7,8,3], James T. Carlton[9], Wayne Dawson[10], Franz Essl[11,3], Llewellyn C. Foxcroft[3,12], Piero Genovesi[13,3], Jonathan M. Jeschke[14,15,16], Ingolf Kühn[17,18,19], Andrew M. Liebhold[20,21], Nicholas E. Mandrak[22], Laura A. Meyerson[23], Aníbal Pauchard[24,25], Jan Pergl[1], Helen E. Roy[26], Hanno Seebens[27], Mark van Kleunen[28,29], Montserrat Vilà[30,31], Michael J. Wingfield[32] and David M. Richardson[3]



Aukema et al. 2010, *BioScience*, DOI 10.1525/bio.2010.60.11.5

Increase climate benefits of harvested wood products

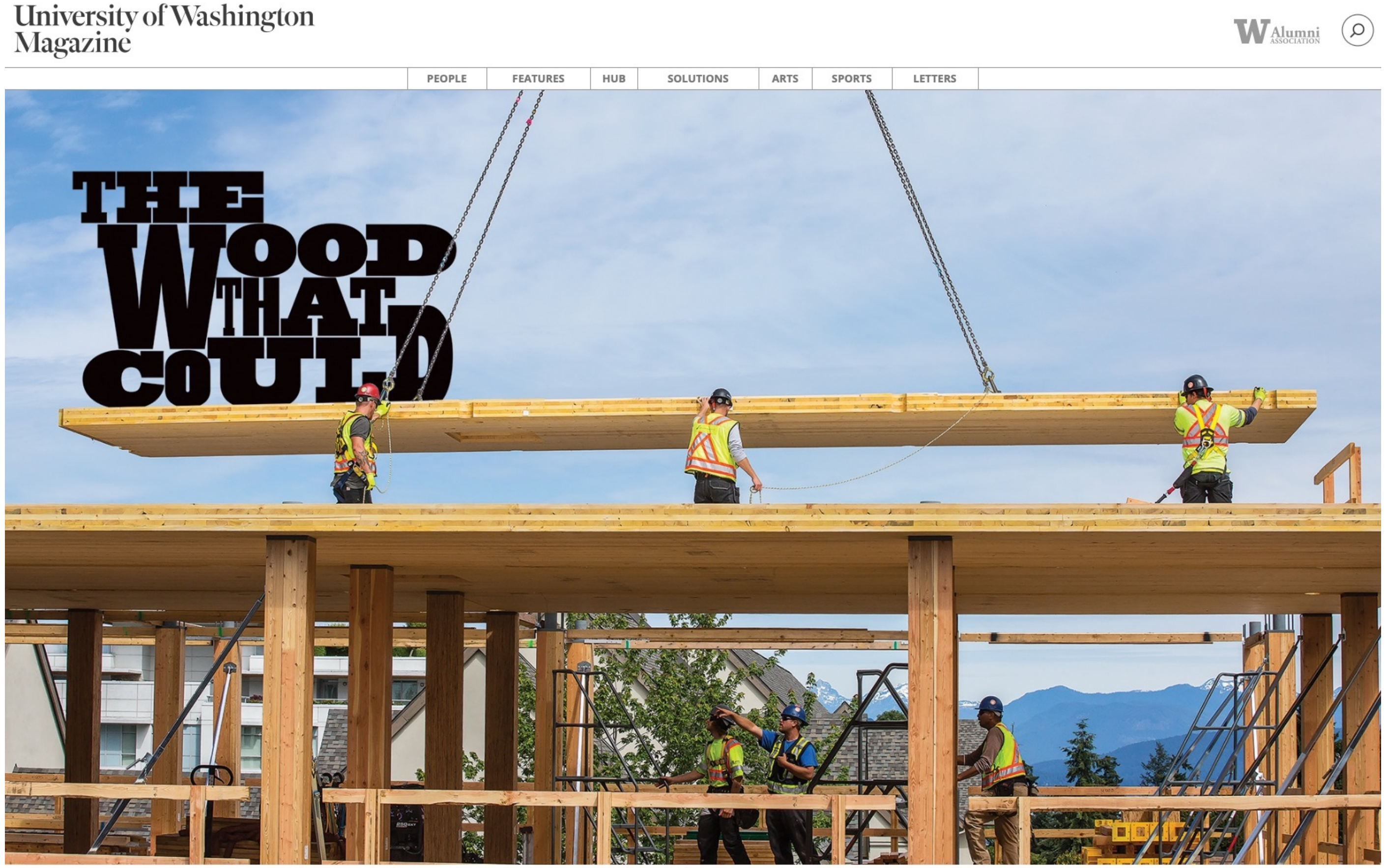
Wood products may have additional climate benefits through energy & product substitution



Planned disturbances

Increase climate benefits of harvested wood products

Wood products may have additional climate benefits through energy & product substitution



Planned disturbances

Cross-laminated timber could 'forge new links between lands and people'

Increase climate benefits of harvested wood products

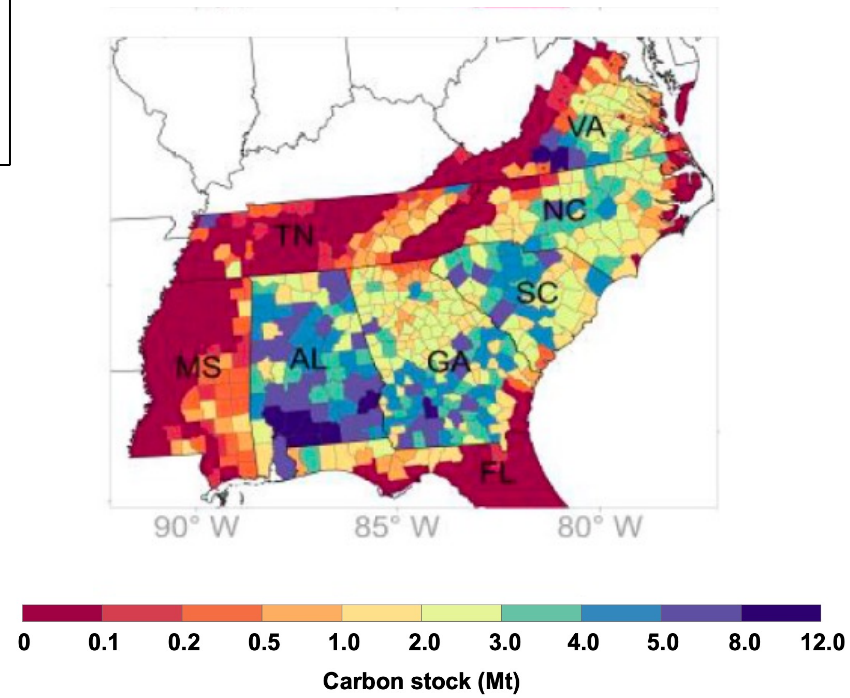
Innovative, commercial pine planting could mitigate ~ 3-4 billion metric tonnes CO_2e over 100 years

PNAS RESEARCH ARTICLE | ENVIRONMENTAL SCIENCES ECOLOGY OPEN ACCESS

Climate-smart forestry through innovative wood products and commercial afforestation and reforestation on marginal land

Bingquan Zhang[a,1], Kai Lan[a,1], Thomas B. Harris[b], Mark S. Ashton[b], and Yuan Yao[a,b,2]

Edited by Yiqi Luo, Cornell University; received December 24, 2022; accepted April 25, 2023 by Editorial Board Member Mary K. Firestone



Conclusions

1) Land managers and policy makers are actively discussing "**Carbon forestry**" for **climate** mitigation

2) **Carbon**, **forestry**, and **climate** are deeply entwined and whether we chose to act or not – forest carbon is part of the globe's carbon budget.

3) There are a a host of **Climate**-Smart **Forestry** practices that hold promise for climate adaptation and mitigation

Disclaimer: Carbon should probably not be the *primary* reason to manage forests.








Photos by Katy Wilkens, Mike Arney, Erik Karits, Sebastian Pichler, Karsten Winegart, Alex Reynolds on [Unsplash].





Sara Kuebbing
Director of Research
Yale Applied Science Synthesis Program

sara.kuebbing@yale.edu