United States Department of Agriculture

Sustainable Forest Management for increasing soil carbon sequestration with biochar

Carlos Rodriguez Franco*

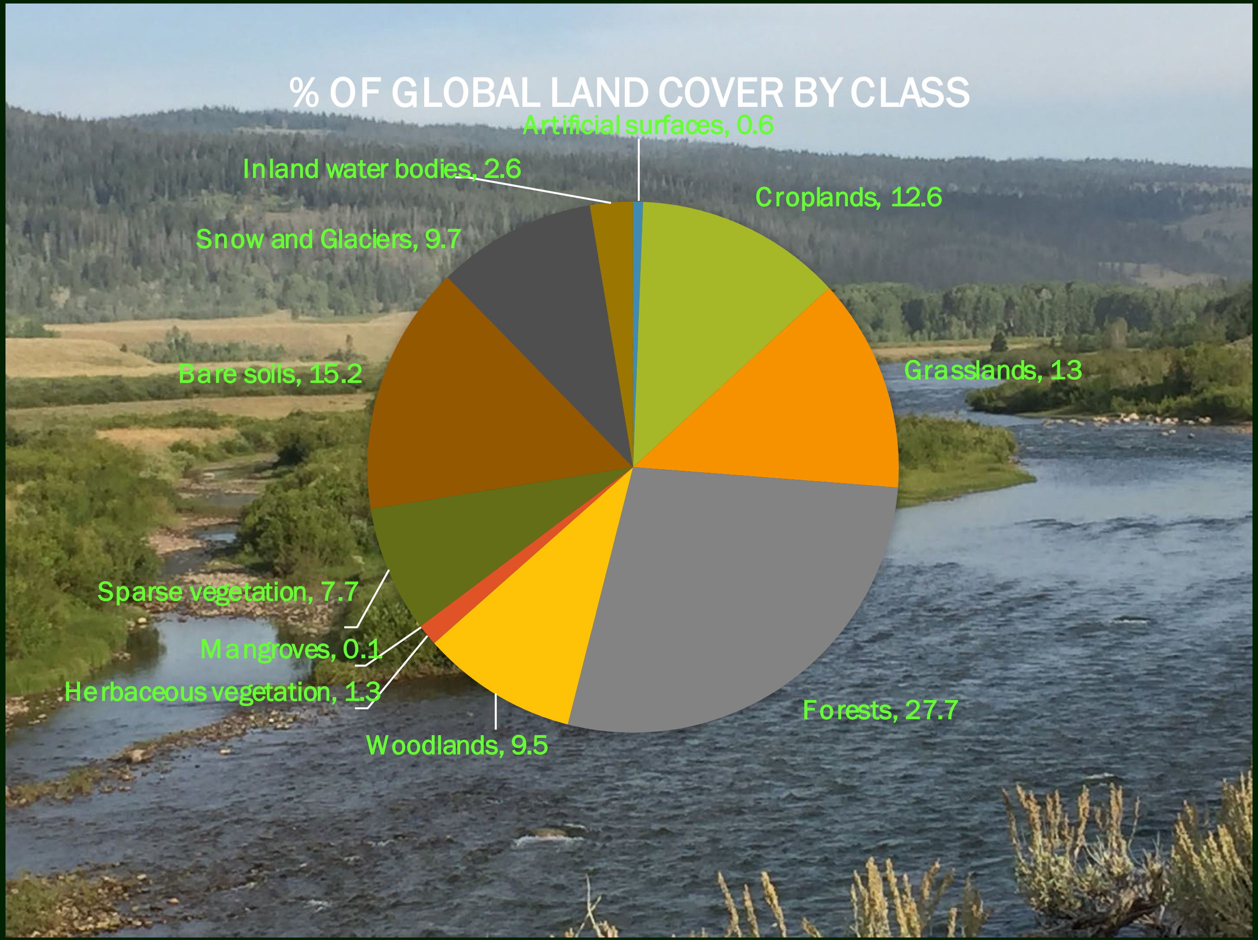
Bioenergy's Role in Soil Carbon Storage Workshop
U.S. Department of Energy (DOE), Bioenergy Technologies Office (BETO) March 28th–29th, 2022

Forest Service Research and Development

* Senior Forester, Forest Service Research and Development.
March 29th, 2022

United States Department of Agriculture

Soil Main Facts



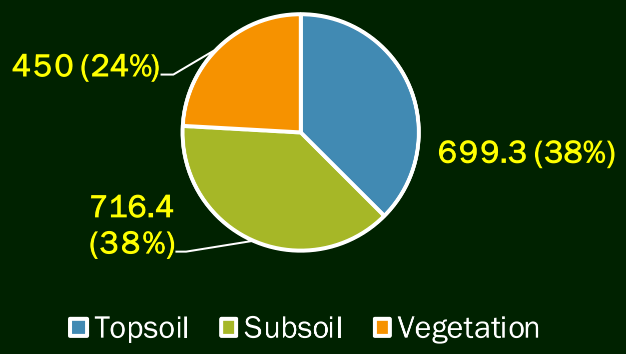
The land area of the world is 13.003 billion ha.

Source: FAO and ITPS. 2015. Status of the World's Soil Resources (SWSR) – Main Report Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy. https://www.fao.org/3/i5199e/I5199E.pdf

USDA United States Department of Agriculture

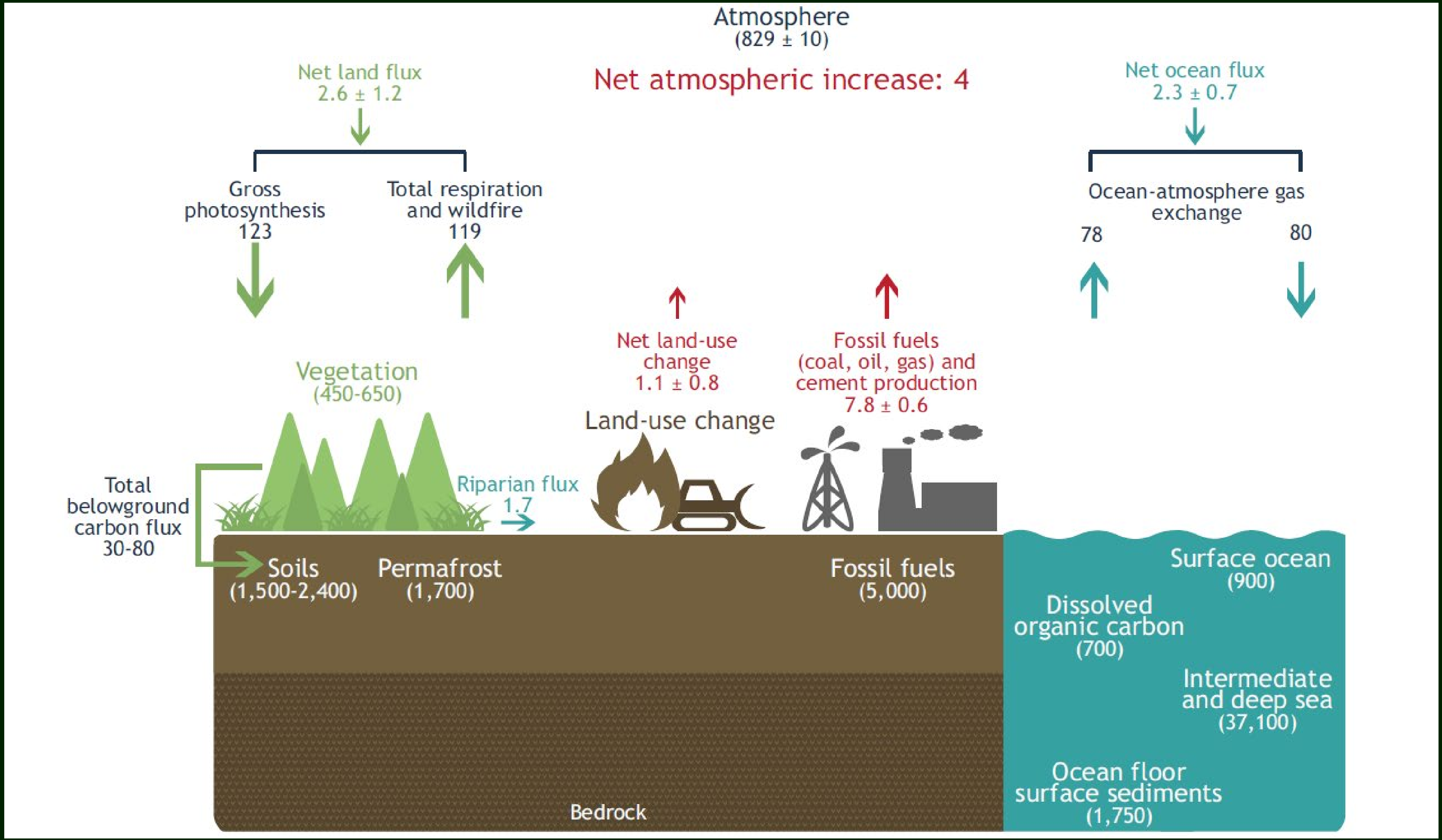
Global carbon cycle. Carbon (Gt C) stocks are denoted in parentheses and shown in gigatons. Fluxes (Gt C per year) are associated with arrows and shown in gigatons per year.

Global Carbon amount in Soil and Vegetation (Gt)



Upper level for Carbon vegetation is 650Gt, and for Soil Carbon is 2400 Gt

Jörn PW Scharlemann, Edmund VJ Tanner, Roland Hiederer & Valerie Kapos. (2014) Global soil carbon: understanding and managing the largest terrestrial carbon pool, Carbon Management, 5:1, 81-91, DOI: 10.4155/cmt.13.77

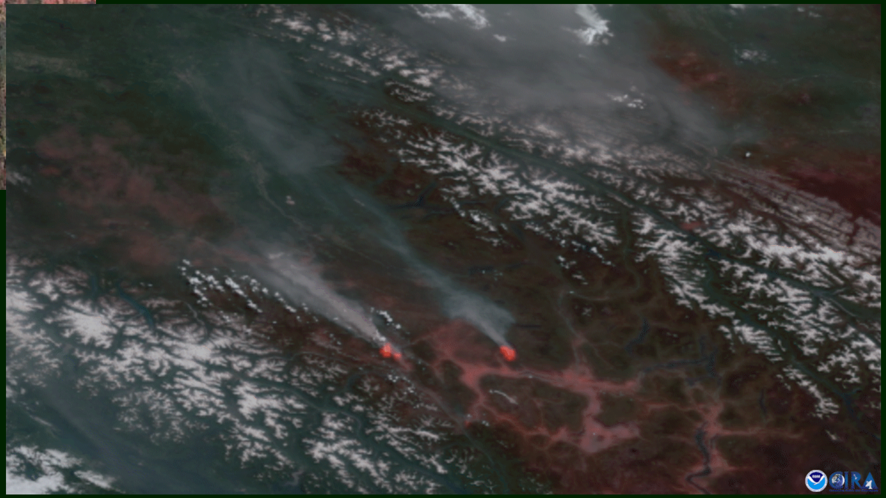


Forest Service Research and Development

Source: Janowiak, M.; Connelly, W. J.; Dante-Wood, K; Domke, G. M.; Giardina, C.; Kayler, Z.; Marcinkowski, K.; Ontl, T.; Rodriguez-Franco, C.; Swanston, C.; Woodall, C. W.; and Buford, M. 2017. Considering forest and grassland carbon in land management. USDA, Forest Service. General Technical Report WO-95. 69 p. https://www.fs.fed.us/sites/default/files/fs_media/fs_document/update-considering-forestandgrassland-carbonin-landmanagement-508-61517.pdf

Processes affecting vegetation Dynamics

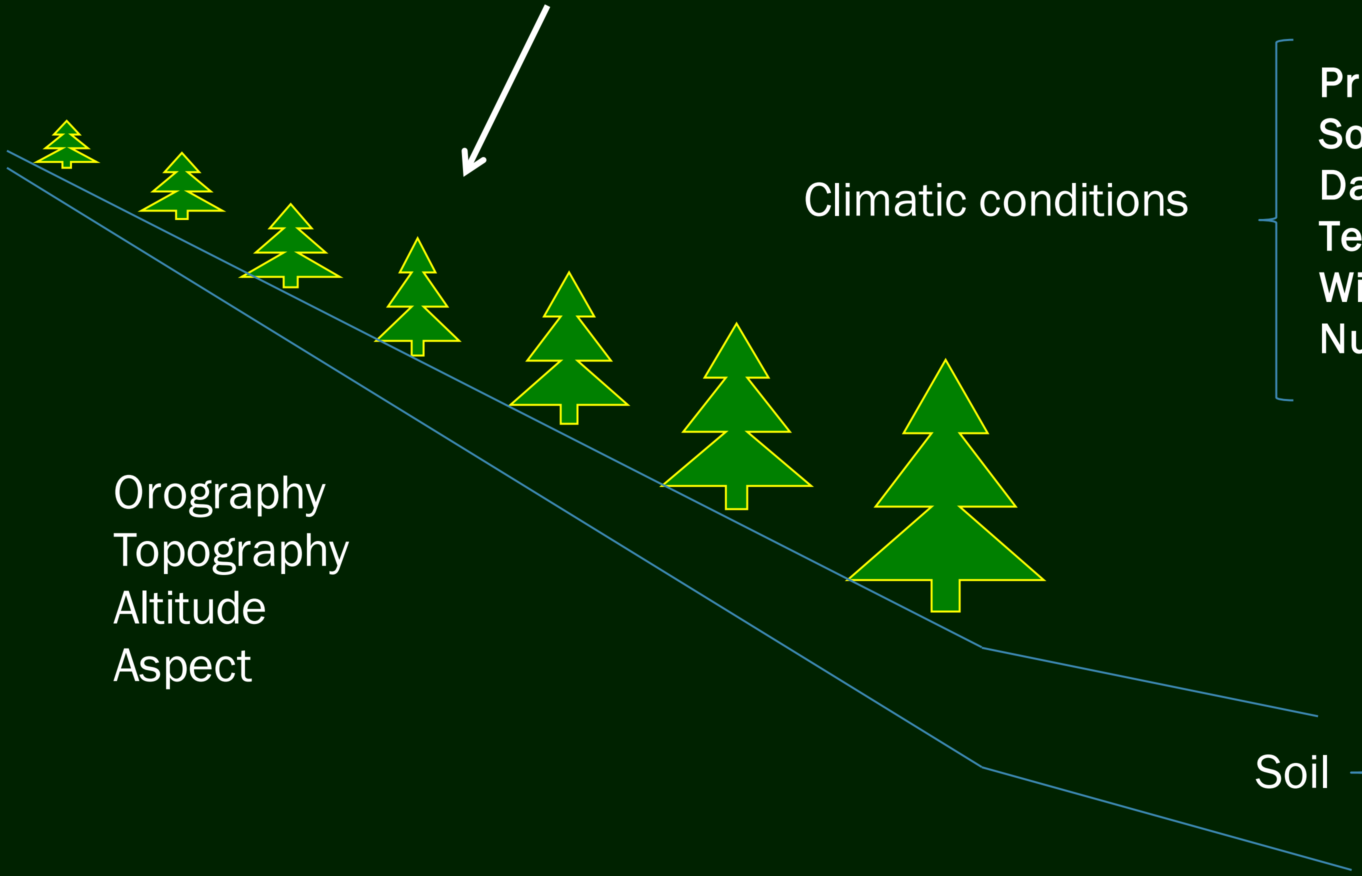
- Warming and crowding increase fire severity in low- to mixed-severity fire regimes.
- Many large fires are in diseased and drought-stressed forests.



- Disturbances Intensity frequency
  - Catastrophic
    - Man made
      - Fire.
      - Grazing
    - Natural
      - Earthquakes,
      - Fire
      - Snowstorms,
      - Hurricanes,
      - Land slides,
      - Tornados,
      - Insect and disease attack
      - Floods
      - Droughts
  - Non - Catastrophic
    - Natural (Same as above, but a lower scale)
    - Man made

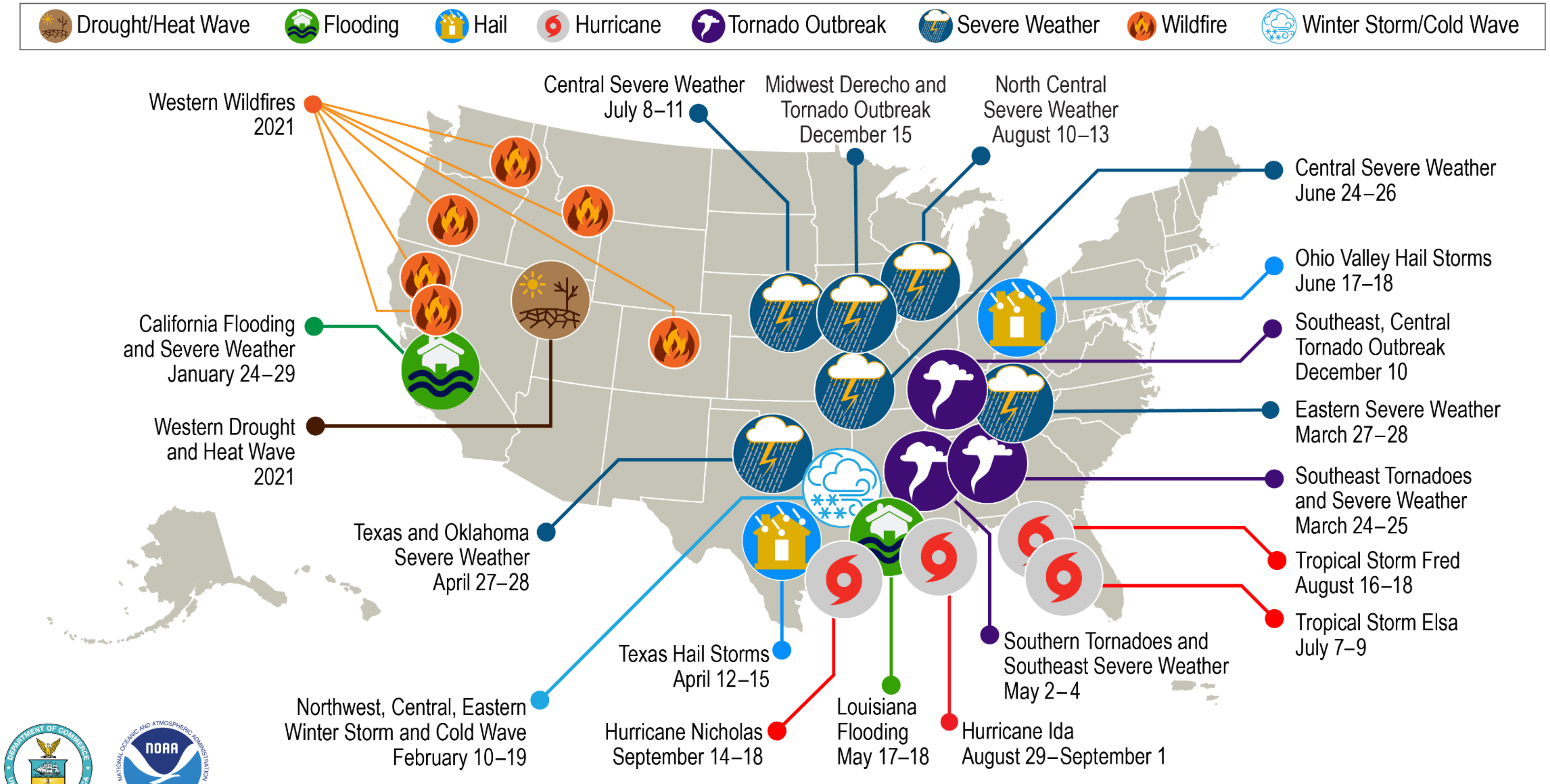
Source: White, S.P. 1979. Pattern, process, and natural disturbance in vegetation. Botanical review 45:229 – 299.

Factors affecting tree growth



USDA
United States Department of Agriculture

U.S. 2021 Billion-Dollar Weather and Climate Disasters



This map denotes the approximate location for each of the ***20 separate billion-dollar weather and climate disasters that impacted the United States in 2021***

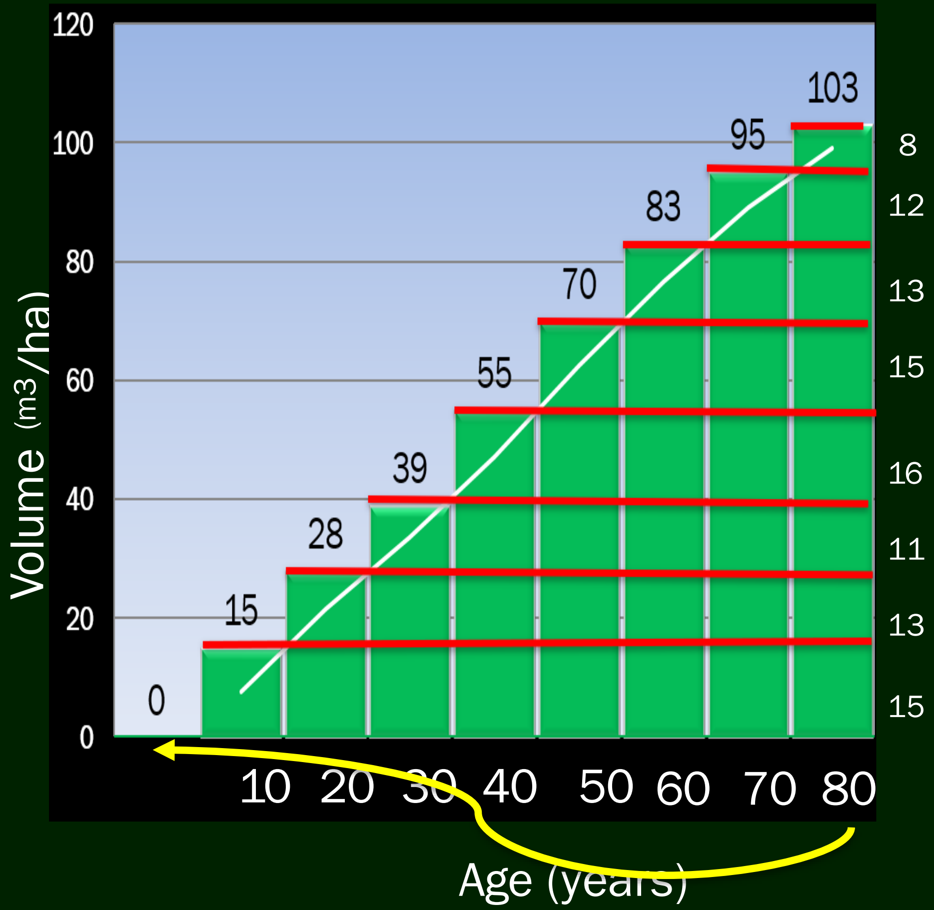
Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/

Forest Service Research and Development

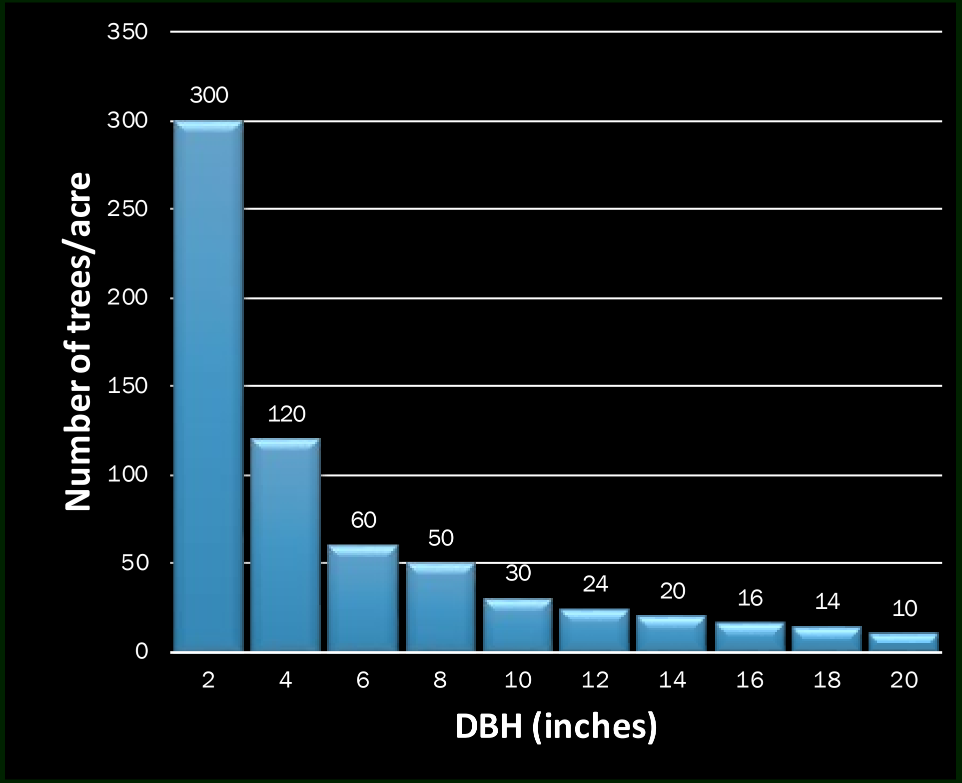
Forest Inventory

- Where are they
- How Are they
- What Quantity are they

The sustainability concept and the normal forest



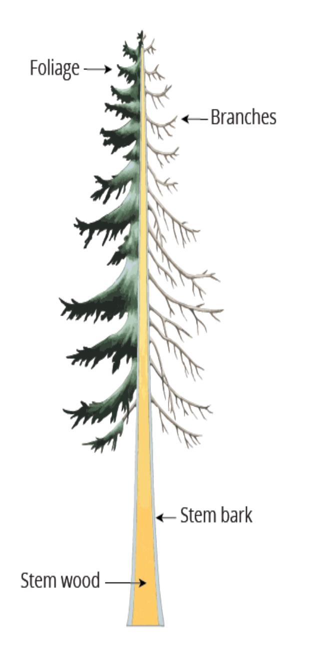
Hypothetical conifer even-aged forest stand



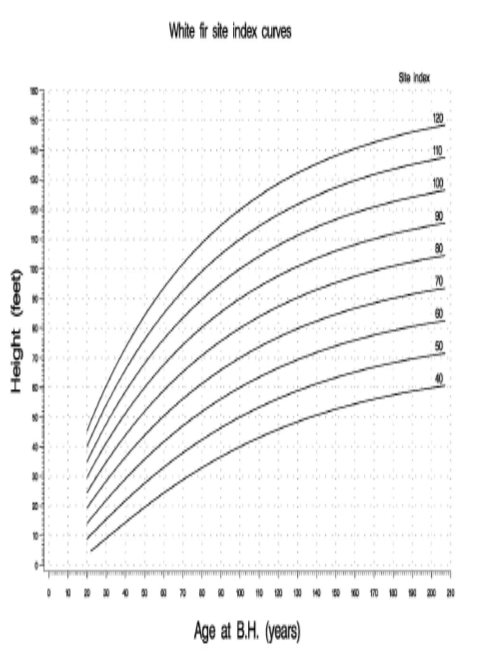
Hypothetical conifer uneven-aged forest stand

Analytical tools for characterization of forest stands (volume tables, allometric relationships, site index, competition indexes, yield tables, simulation models,

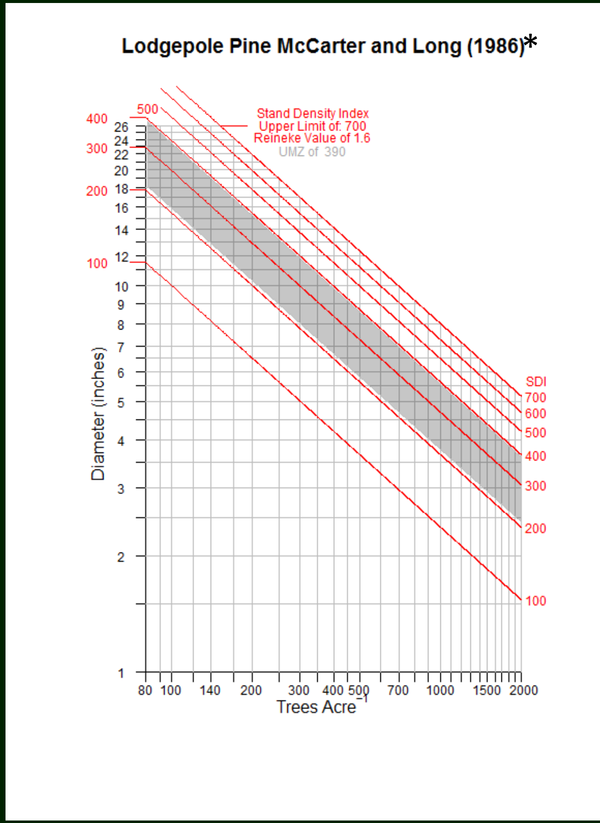
Tree volume*



Site Index**



Stand Density Index***



Initial age	Final age (Years)	Site index 50	60	70	80	90	Projected basal area (sq ft.)
A1	A2	VIM (cubic feet,i. b. ,/acre)					BT2
20	20	312	624	908	1168	1431	80
	25	788	1295	1709	2099	2509	108
	30	1360	1985	2495	2999	3548	130
	35	1927	2615	3200	3804	4476	147
	40	2440	3162	3810	4500	5280	160
	45	2885	3629	4331	5096	5968	169
	50	3266	4027	4776	5606	6557	177
25	25	599	972	1276	1564	1869	80
	30	1101	1590	1992	2391	2828	103
	35	1626	2191	2676	3179	3739	122
	40	2123	2738	3295	3890	4563	138
	45	2568	3221	3841	4518	5291	150
	50	2960	3643	4317	5067	5926	160
	55	3300	4008	4732	5544	6479	168

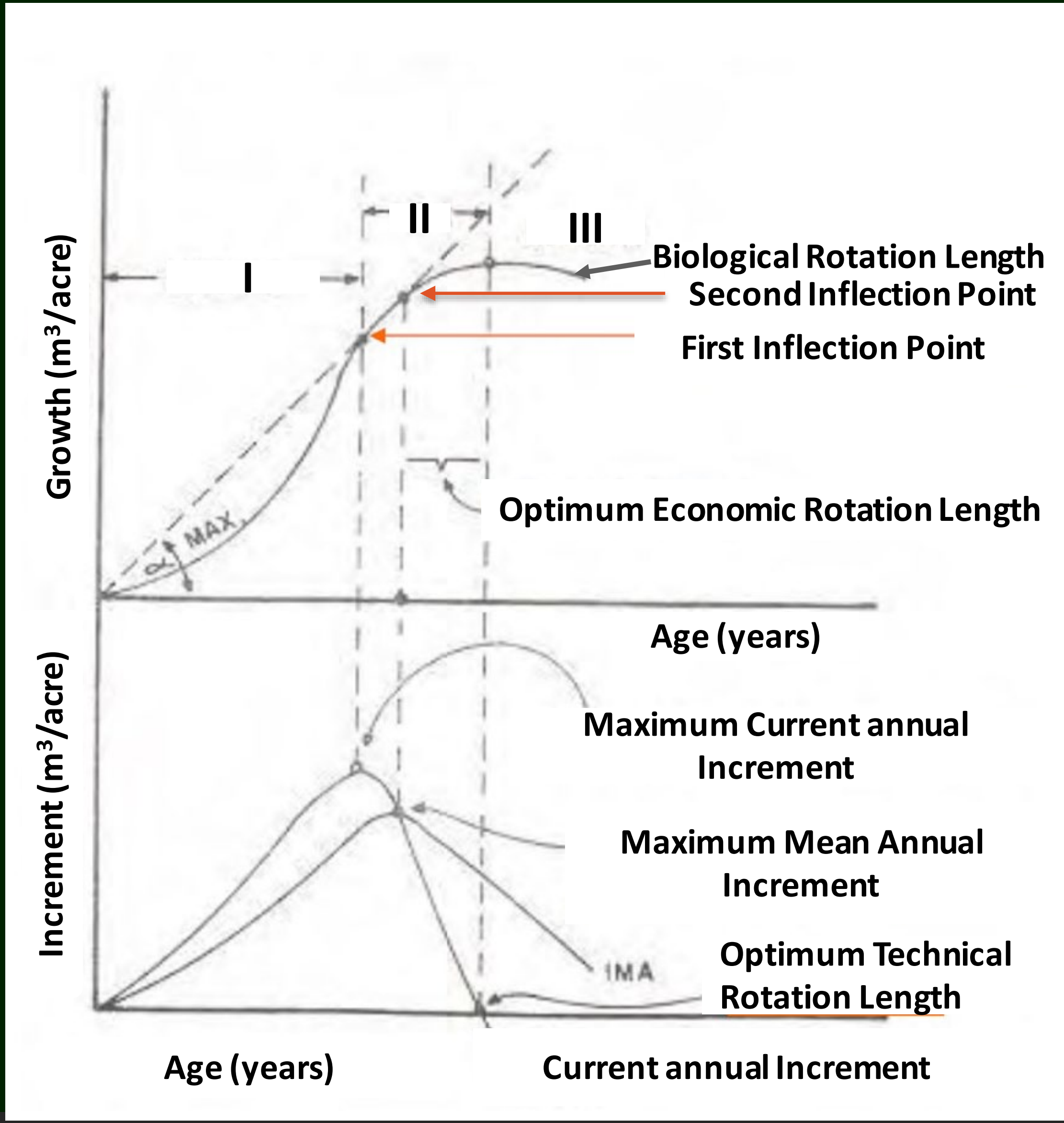
Current and projected merchantable cubic foot volumes, i b, (VIM) and projected total basal area (BT2) for natural even-aged s-ands of long leaf pine in the East Gulf, initial basal area (BT1) = 80 square feet****

*Source: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/forest/sof2020/indicators/Tree_diagram.png

**Source: Mathiasen, L. R., Olsen, K.W., and Edminster, B. C. 2006. Site Index Curves for White Fir in the Southwestern United States Developed Using a Guide Curve Method. *West. J. Appl. For. 21(2):87–93.* https://doi.org/10.1093/wjaf/21.2.87

***Source: Ritchie, M. 2016. Standview. https://www.fs.fed.us/psw/tools/standview/

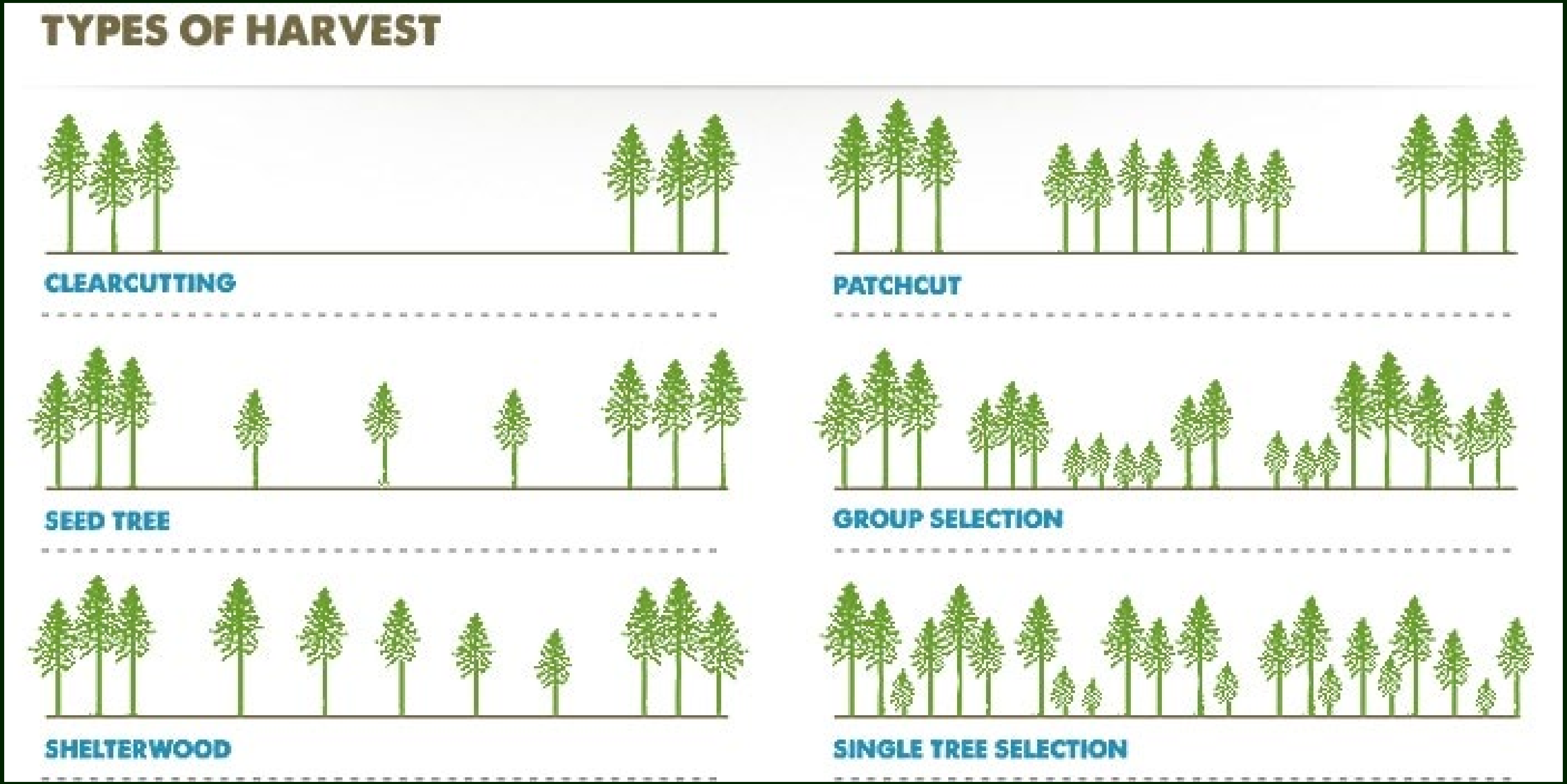
****Source: Farrar, M. R. Jr. 1993. Growth and Yield In Naturally Regenerated Longleaf Pine Stands. *Proceedings. of the Tall Timbers Fire Ecology Conference*, No. 18, The Longleaf Pine Ecosystem: ecology, restoration and management, edited by Sharon M. Hermann, Tall Timbers Research Station, Tallahassee, FL. https://talltimbers.org/wp-content/uploads/2014/03/Farrar1993_op.pdf



Simulation Models

- Stand level
- Distance Independent tree level
- Distance dependent tree level

Silvicultural Systems



Oregon Forest Resources Institute. https://oregonforests.org/faq

Forest Management and Silviculture are the best approach to healthy, resilient forests

Increasing spatial heterogeneity (in terms of composition, age, structure, and spatial distribution).

*Photo source: Anderson, D.P., 2007. Early Understory Vegetation Responses to Initial Thinning: The H.J. Andrews Uneven-aged Management Project. Pacific Northwest Station. National Silviculture Workshop. Alaska.

Ponderosa pine Thinning*

Before

After

*Source: Barbara J. Bentz, Christopher J. Fettig and Marilyn Buford[3]. 2009. Climate Change, Bark Beetles, and Bioenergy in the Western United States. PowerPoint Presentation

Forest Management Decisions

- Passive : Wilderness Areas Limited actions (ecological intervention for restoration of natural character
- Active Forest Management
  - Traditional Forest Management
  - Adaptive Forest Management
  - Forest Management for Mitigation of Impacts of Climate Change

USDA
United States Department of Agriculture

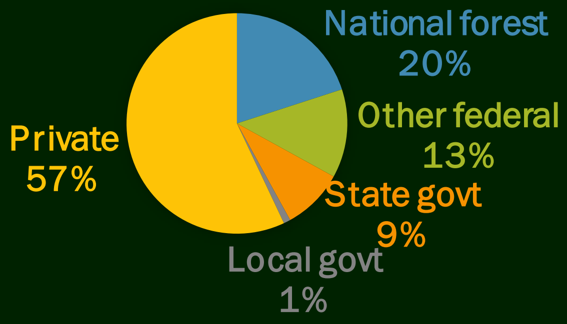
United States Forest Resources

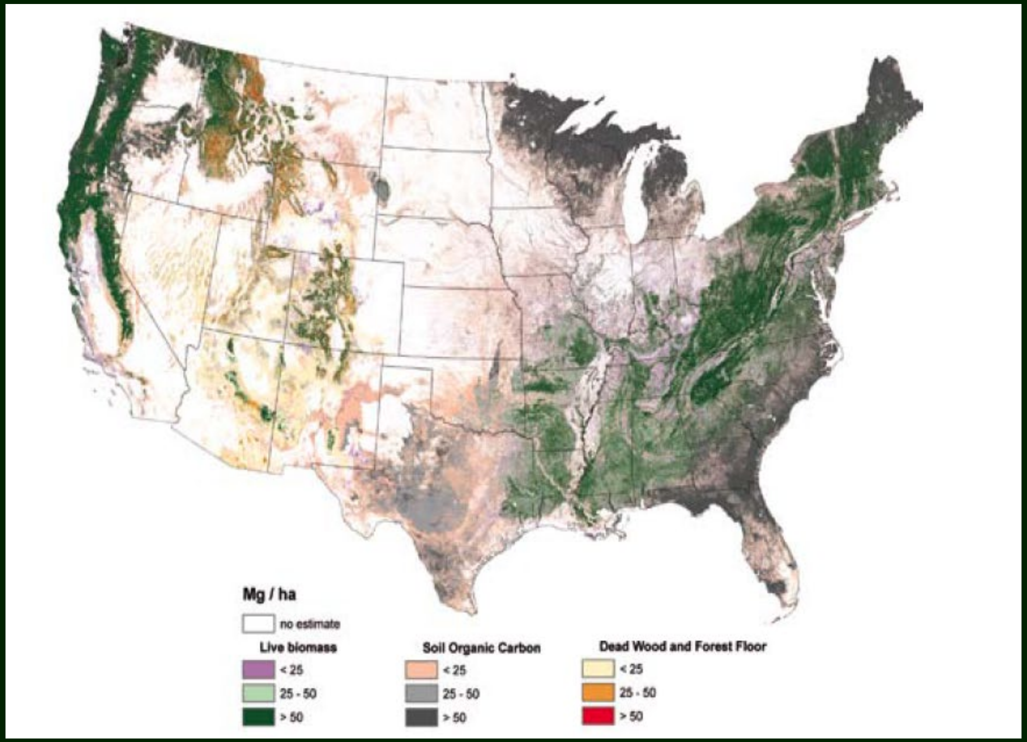
- The United States has about 7.5 percent of the world's forests, a little over 300 million hectares.

- 10% of the world's timber inventory.

- Roughly 11 million acres are harvested each year.

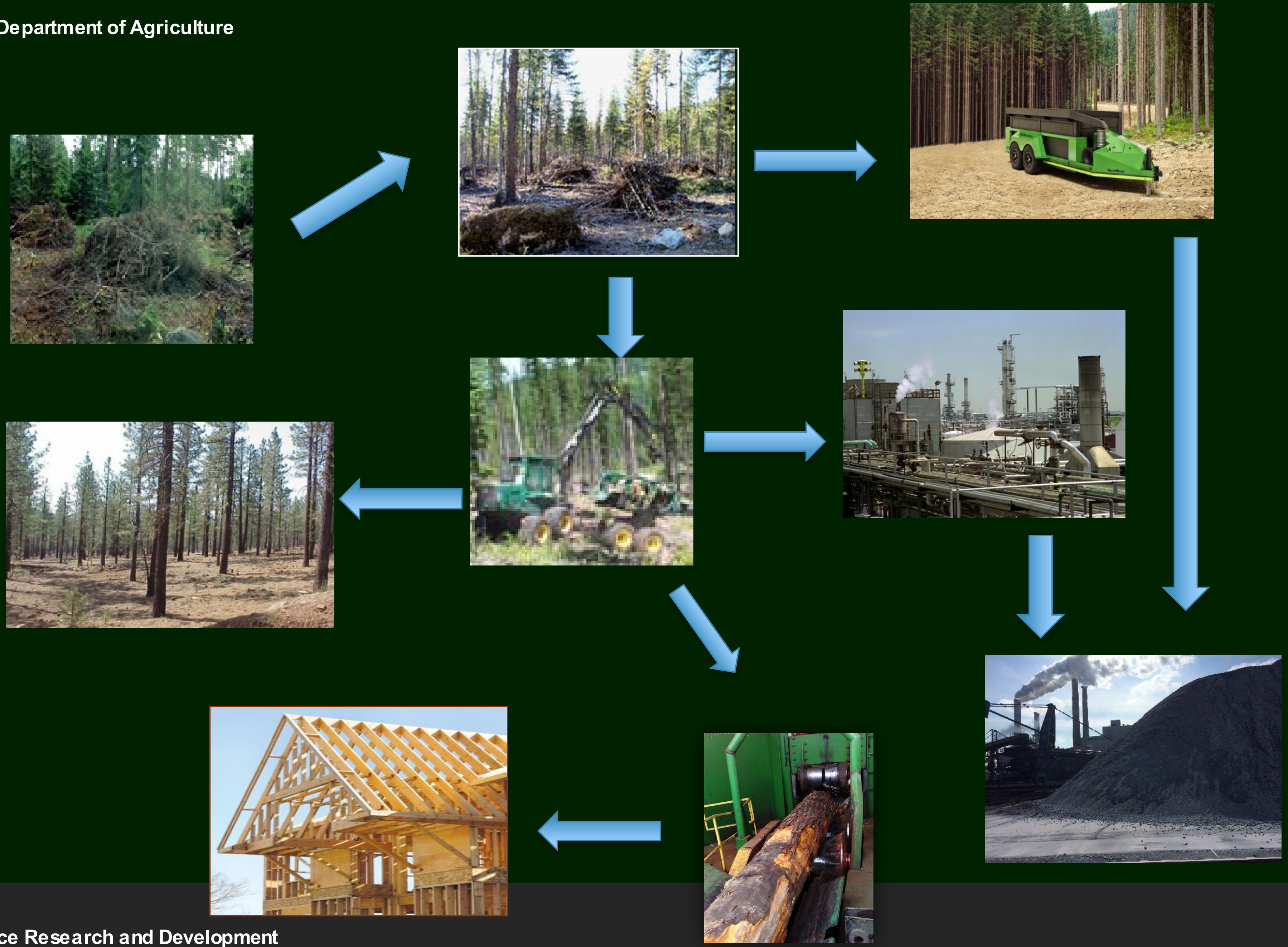
Ownership of ~300 million hectares of forest in the US





Forest carbon pool which constitute the plurality of forest carbon at each pixel across the conterminous U.S.: live biomass, soil organic carbon, or detritus (dead wood and forest floor) (Wilson et al. 2013).

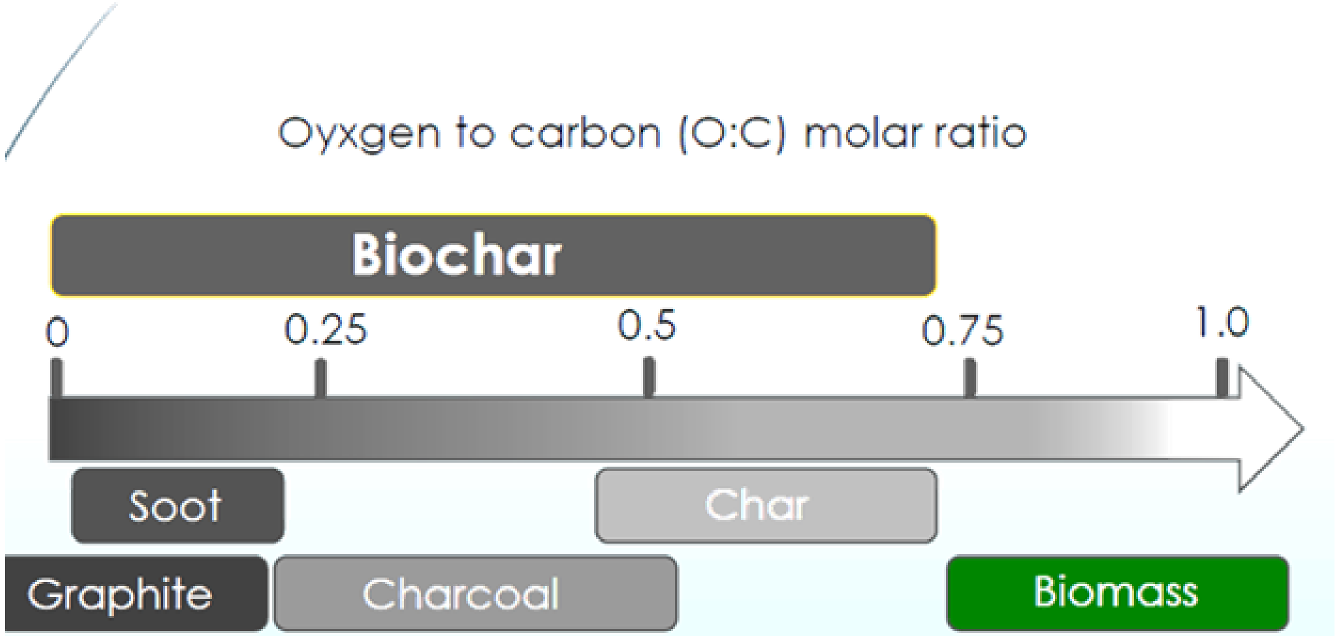
https://cbmjournal.biomedcentral.com/track/pdf/10.1186/1750-0680-8-1



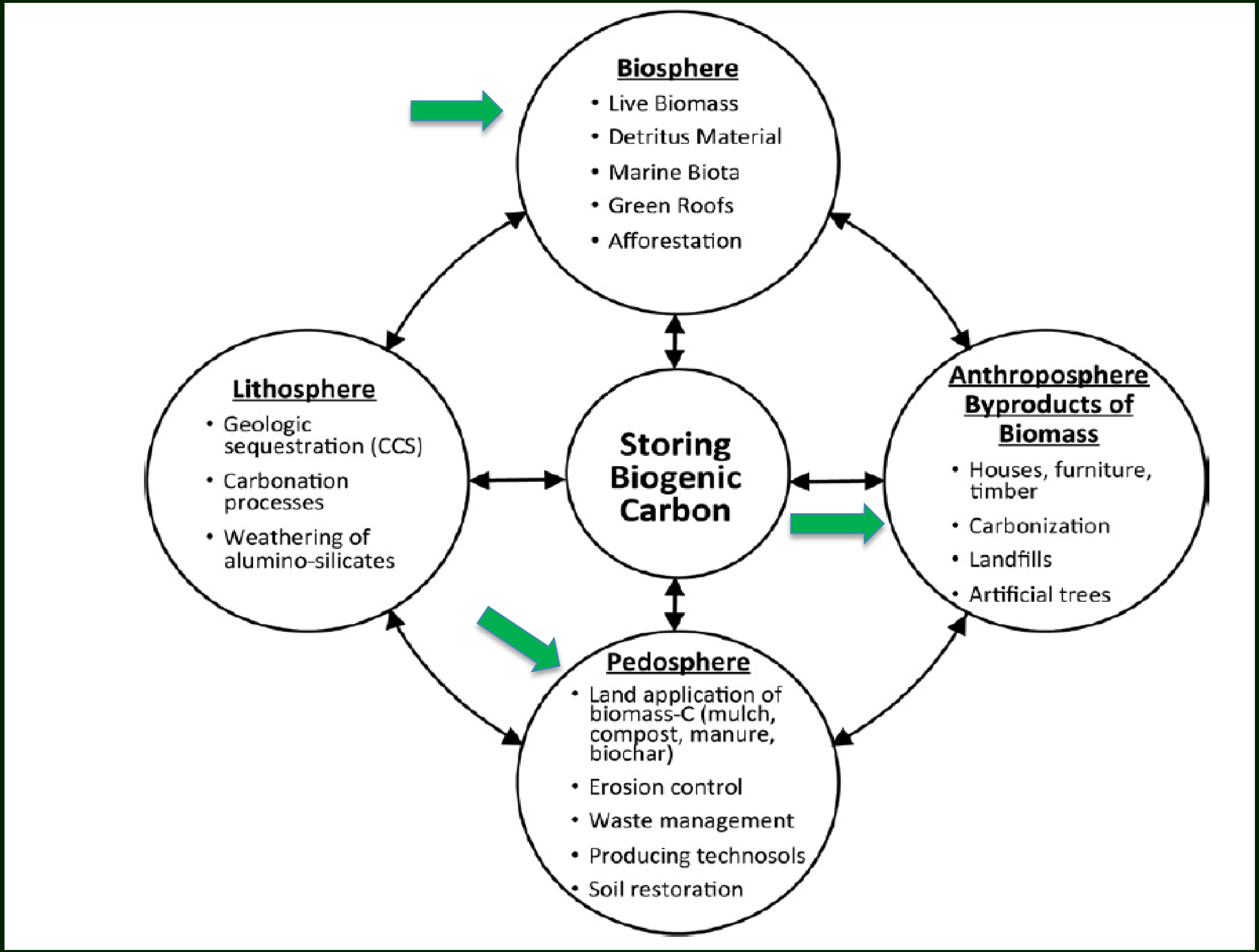
Black carbon and biochar

Black carbon is a range of solids resulting from thermal conversion of any carbon containing materials

Biochar is NOT a new division or material



Source: Heather Nobert. Biochar 101. Nebraska Forest Service. https://nfs.unl.edu/documents/TCW2017/TCW%20Biochar%20101.pdf



Source Rattan Lal. 2016. Biochar and Soil Carbon Sequestration. Agricultural and Environmental Applications of Biochar: Advances and Barriers. SSSA Special Publication 63. M. Guo, Z. He, and S.M. Uchimiya, editors.

The Importance of Biochar in Carbon Sequestration to mitigate Climate Change

- Large amounts of black charcoal derived C stocks remain in soils today, hundreds and thousands of years after they were abandoned.
- The total C storage is as high as 250Mg C ha^{-1} m^{-1} compared to typical values of 100Mg C ha^{-1} m^{-1} in Amazonian soils derived from similar parent material (Glaser et al. 2001).
- Lehmann, et., al., (2006) their global analysis indicated that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash-and-burn is replaced by slash-and-char.
- Agricultural and forestry wastes such as forest residues, mill residues, field crop residues, or urban wastes add a conservatively estimated 0.16 Pg C yr^{-1}.
- Biofuel production using modern biomass can produce a biochar by-product through pyrolysis which results in 30.6 kg C sequestration for each GJ of energy produced.
- Using published projections of the use of renewable fuels in the year 2100, bio-char sequestration could amount to 5.5–9.5 Pg C yr^{-1} if this demand for energy was met through pyrolysis, which would exceed current emissions from fossil fuels (5.4 Pg C yr^{-1}).

Lehmann, J., Gaunt, J., and Rondon, M. 2006. Bio-char sequestration in terrestrial ecosystems: a review. Mitigation and Adaptation Strategies for Global Change (2006) 11: 403–427. DOI: 10.1007/s11027-005-9006-5

Glaser, B., Haumaier, L., Guggenberger, G. and Zech, W.: 2001, 'The Terra Preta phenomenon – A model for sustainable agriculture in the humid tropics', *aturwissenschaften* **88**, 37–41.

Forest Management Activities to Increase Carbon Sequestration or Reduce Emissions and where biochar could have impact

- Afforestation
- Reforestation
- Forest restoration
- Improved forest management (through silvicultural practices and other cultural practices)
- Short-rotation biomass energy plantations
- Forest preservation (avoiding deforestation)
- Mine land reclamation

Benefits of producing biochar from forest Management activities

- Beneficial on all federal lands by increasing resilience for better adaptation to climate change, increasing forest productivity, decreasing insect and disease attacks, and increasing other environmental benefits such as C sequestration, and water retention.

- In addition, high-C biochars contain 70-90% C and, when used as a soil amendment, is a perfect tool for sequestering C within the mineral soil.

- If biomass is sustainably harvested, biochar supply chains can be C-negative. Furthermore, when net carbon balance in the forest ecosystem is positive, biochar can actively remove atmospheric CO_2, with potentially major implications for mitigation of climate change.

The Potential of National Forests to produce biochar

- According to several authors, biomass feedstock is dried to less than 10% water in order to minimize the water in the resulting liquid product, and pyrolysis produces 60 to 75% w/w bio-oil, 15 to 25% w/w solid biochar, and 10 to 20% w/w non-condensable gases, but exact proportions are largely dependent on the feedstock and process temperatures.
- When considering the 334 million tons of residues per year that could be produced in the US, and the conversion factor of 15 to 25 % w/w of solid biochar resulting from the pyrolysis the potential production of biochar from National Forests ranges from 50.1 to 83.5 M MT yr^{-1}. T
- Biochar use on these sites will provide additional benefits of climate change mitigation, use dead trees from drought, disease, insect, or wildfire and will allow land managers to reduce wildfire risk, while improving habitat, decreasing soil and water pollution, and promoting rural economies

Sources:
Buford A.M., and Neary, D.G. 2010. Sustainable Biofuels from Forests: Meeting the Challenge, The Ecological Society of America, http://esa.org/biofuelsreports.
Bridgewater, A.V. 2004. Biomass fast pyrolysis. Thermal Science 8:21-49. https://doi.org/10.2298/TSCI0402021B
Mohan, D., Pittman, U.C., and Steele, H.P. 2006, Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. *Energy & Fuels* 2006 *20* (3), 848-889. https://doi.org/10.1021/ef0502397

Benefits from Forest Management in U.S.

The main benefits of forest management for increasing carbon sequestration in forest ecosystems to rural and urban communities are:

- To have sustainable, healthy and resilient forest ecosystems.
- Continue enjoying ecosystem services (recreation, water, wildlife, clean air, others).
- Economic opportunities through jobs.
- Decrease the risk of catastrophic fires to communities.
- Contribute to decrease the impacts of climate change.

Questions?

Carlos.Rodriguez-franco@usda.gov