United States Department of Agriculture

2024 North American Biochar Conference
USBI
California, USA

What we know about carbon and forests

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What is Carbon? And its relationship with Climate Change

LibreTexts. 2024. General Biology (Boundless). 867 webpages. California State University Affordable Learning Solutions Program. https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_General_Biology_(Boundless)/zz%3A_Back_Matter/21%3A_Detailed_Licensing.

Britannica, The Editors of Encyclopedia. "carbon". *Encyclopedia Britannica*, 15 Nov. 2023 https://www.britannica.com/science/carbon-chemical-element Accessed 3 January 2024.

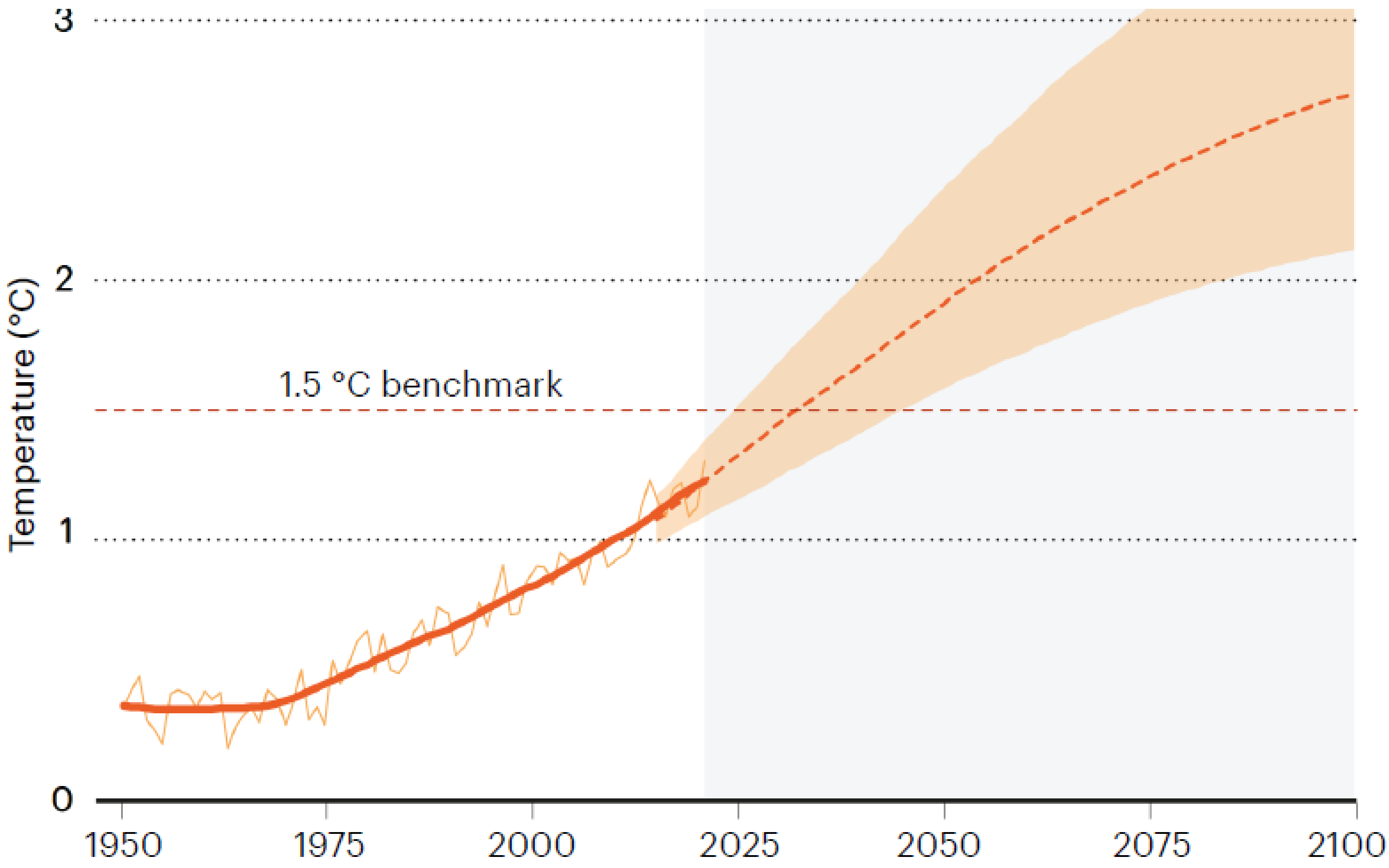
- **Carbon is one of the most common elements encountered in the universe.**
- **Carbon is the fourth most abundant element by mass. It is involved in every known life form for example is the second most abundant element by mass in the human body after oxygen.**
- **Carbon abundance, carbon-based organic compounds and its polymers makes it the chemical foundation of all life as it is known. There are one million organic compounds containing only carbon and hydrogen.**
- **When a carbon atom combines with two oxygen atoms makes carbon dioxide; one of the greenhouse gases causing warming on earth.**

Brief CO_2 evolution on earth

- The amount of CO_2 four billion years ago is unknown, but it is believed to have been as much as 100 times the current atmospheric level. This would have been necessary to keep the Earth's surface temperature above freezing, because of reduced solar luminosity.
- In the Late Pliocene (3.264 to 3.025 million year ago) atmospheric CO_2 concentrations were comparable to present-day values (~400 ppm), and estimated global mean temperatures were elevated by 2–3 °C relative to the pre-industrial period.
- Assessments conducted 10 years ago indicated that during the last 800 thousand years, atmospheric CO_2 ranged from 300 ppm in the interglacial period to a minimum of 180 ppm in the glacial periods.
- In 2011measurements of ice cores revealed GHG concentrations of 390.5 ppm $C0_2$ exceeding the range of measurements for the past 800 thousand years.
- NOAA found in 2022 global average atmospheric CO_2 was 417.06 ppm, setting a new record high, and in May 2023 424 ppm , and currently estimated at 422.5 ppm.
- The measured increases have resulted in 2023 being the warmest year on record with a temperature that is approximately 1.5°C above pre-industrial levels .

Sources: 1) https://doi.org/10.1007/BF00933642; https://doi.org/10.1016/0301-9268(87)90001-5; **2)** https://doi.org/10.1038/s41586-019-1543-2; **3)** https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter05_FINAL.pdf; **4)** https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide#:~:text=In%20May%202023%2C%20carbon%20dioxide,people%20are%20burning%20for%20energy; **5)** https://gml.noaa.gov/ccgg/trends/weekly.html; **6)** https://climate.copernicus.eu/global-climate-highlights-2023

temperatures hit nearly 1.3 °C above preindustrial levels in 2022 and are expected to reach even higher this year. At current trends, the world could surpass 1.5 °C of warming within a decade, if not sooner. Assuming moderate emissions into the future, climate models assessed by the Intergovernmental Panel on Climate Change project a range of warming (orange) by 2100 that is well above 2 °C.

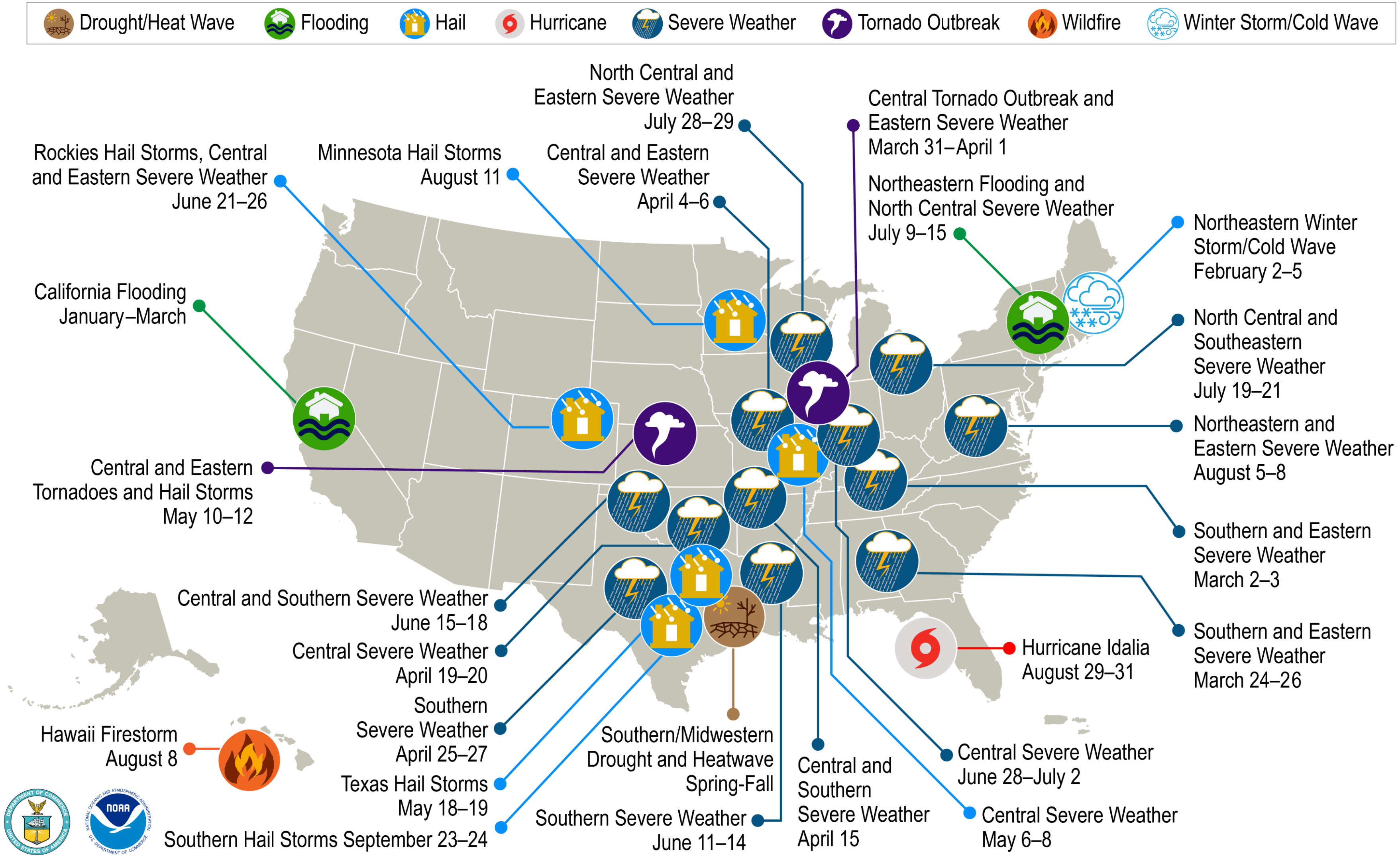


Source: Berkeley Earth

Source: Tollefson, J. 2023. Is it too late to keep global warmingbelow 1.5 °C?The challenge in 7 charts. https://www.nature.com/immersive/d41586-023-03601-6/index.html?utm_source=Live+Audience&utm_campaign=90a078dcce-briefing-dy-20231122&utm_medium=email&utm_term=0_b27a691814-90a078dcce-51619916

U.S. 2023 Billion-Dollar Weather and Climate Disasters

Until November 8thm 2023. There have been 25 confirmed weather/climate disaster events with losses exceeding $1 billion



*This map denotes the approximate location for each of the **25 separate billion-dollar weather and climate disasters that impacted the United States through October 2023.***

•NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2023). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

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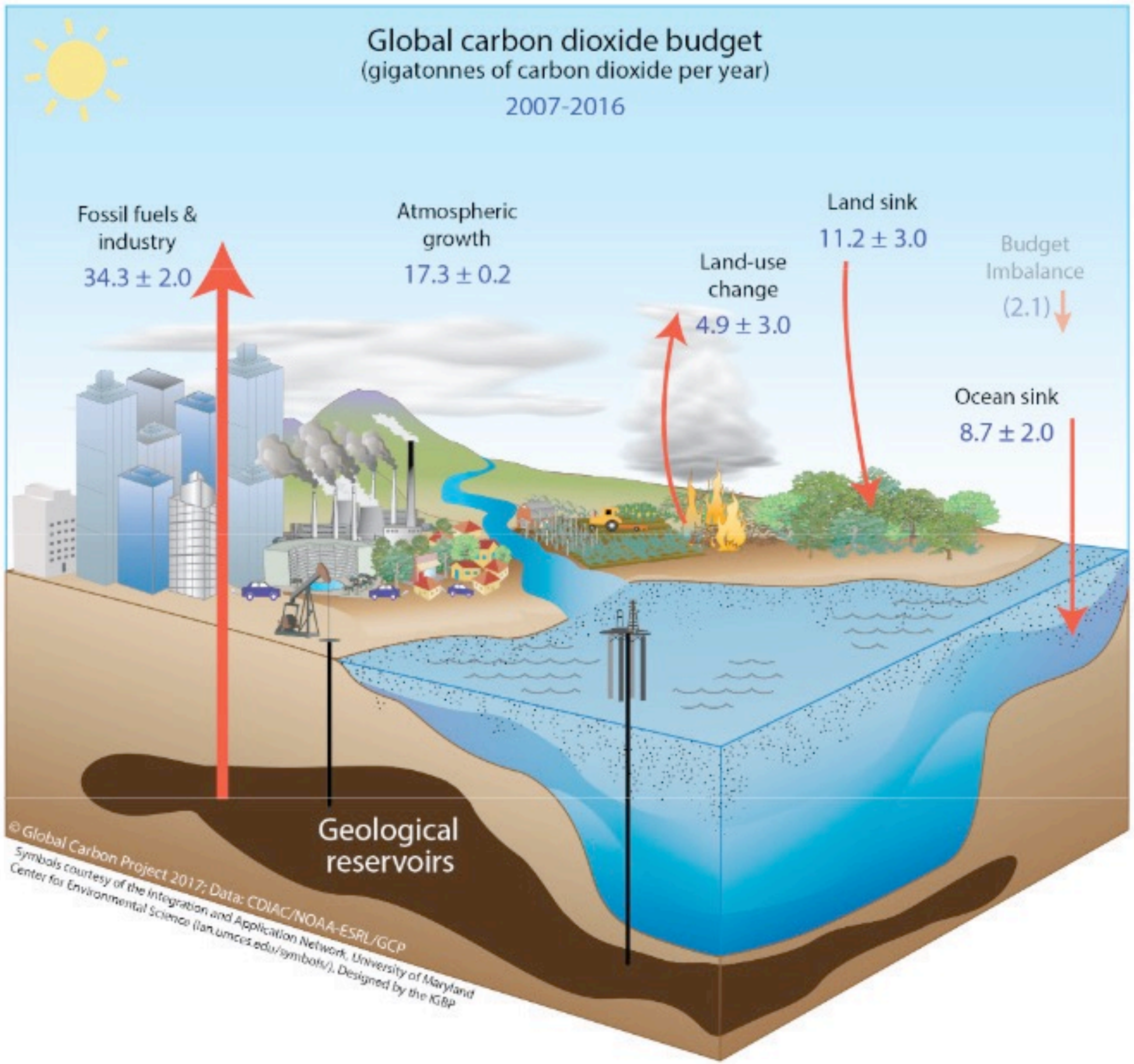


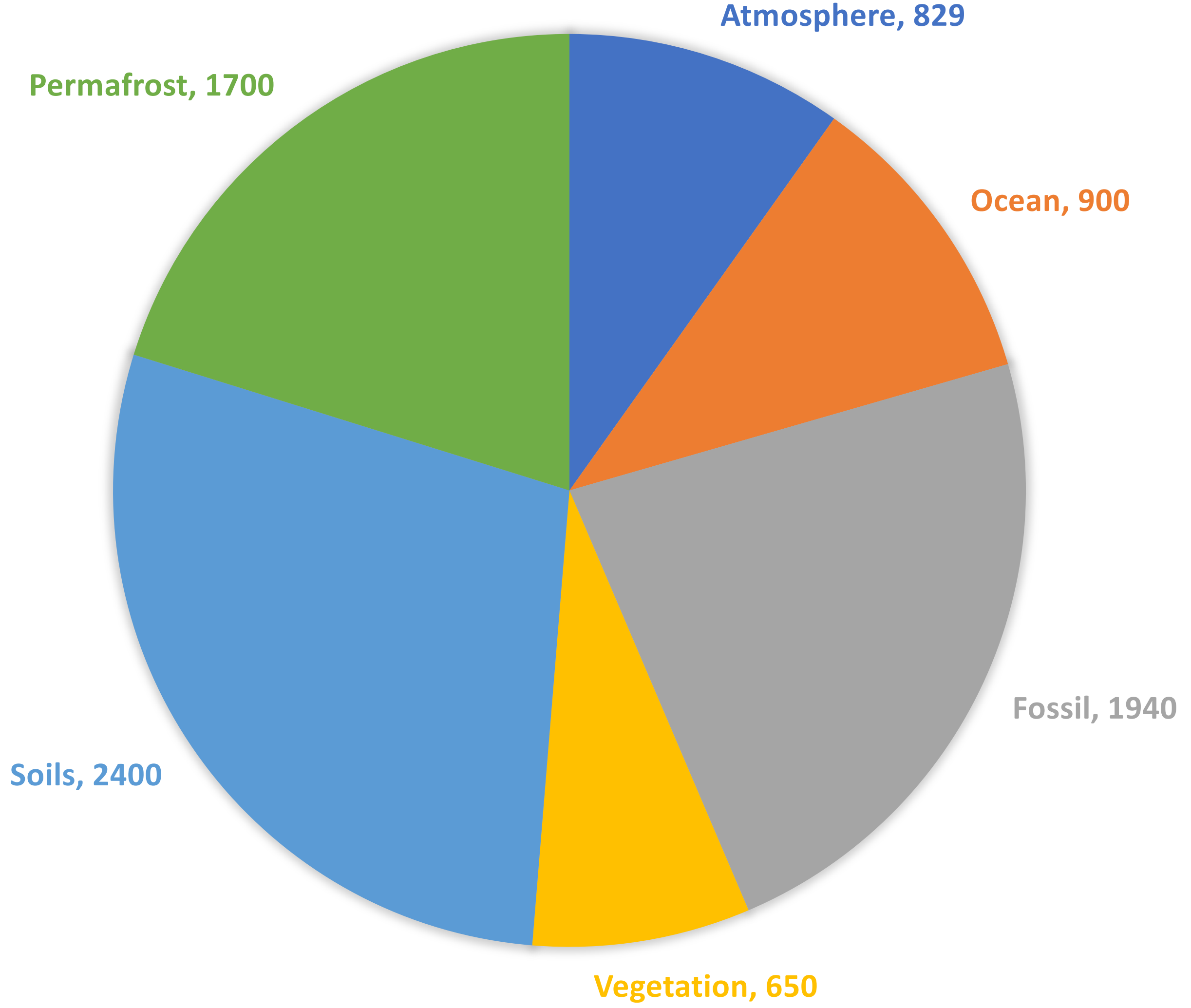
SOURCE: Le Quéré et al., 2018.National Academies of Sciences, Engineering, and Medicine. 2019. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

Global carbon dioxide budget.

The global carbon budget refers to the mean, variations, and trends in the anthropogenic perturbation of CO2 in the atmosphere since the beginning of the industrial era. It quantifies the input of CO2 to the atmosphere by emissions from human activities, the growth of CO2 in the atmosphere, and the resulting changes in land and ocean carbon fluxes in response to increasing atmospheric CO2 levels, climate change and climate variability, and other anthropogenic and natural changes.

* One PgC equals 1 billion metric tons of carbon (1 Gt C), which is the same amount of carbon as in 3.67 Gt CO2. Further, 1 ppm CO2 equals about 7.82 Gt CO2.

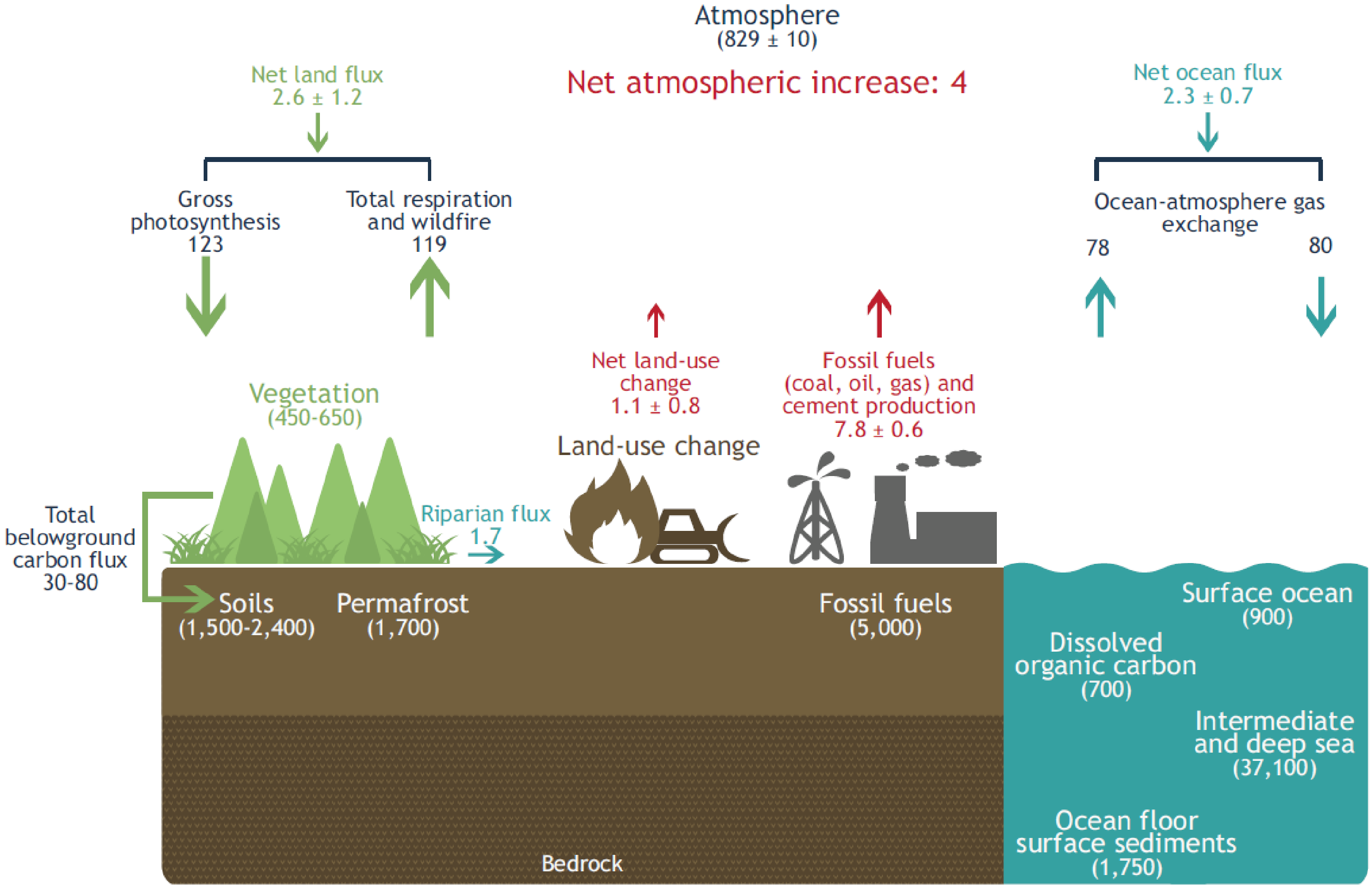
Global Carbon Stocks (PgC)*



It does not consider intermediate and deep sea C and it shows estimated upper amount limits provided by the source

Source: Bruhwiler, L., A. M. Michalak, R. Birdsey, J. B. Fisher, R. A. Houghton, D. N. Huntzinger, and J. B. Miller, 2018: Chapter 1: Overview of the global carbon cycle. In Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report [Cavallaro, N., G. Shrestha, R. Birdsey, M. A. Mayes, R. G. Najjar, S. C. Reed, P. Romero-Lankao, and Z. Zhu (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 42-70, https://doi.org/10.7930/SOCCR2.2018.Ch1.

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.



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

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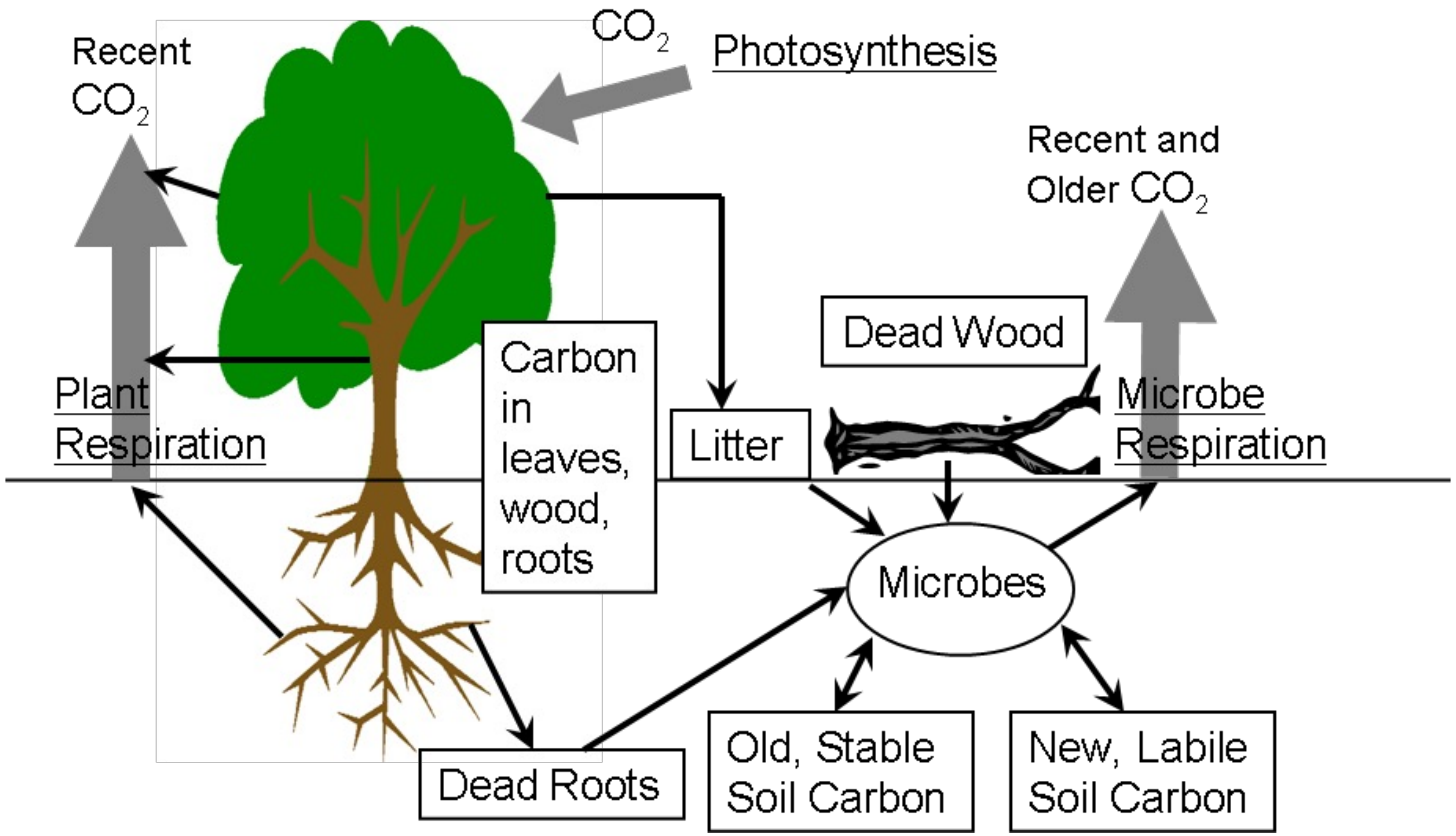
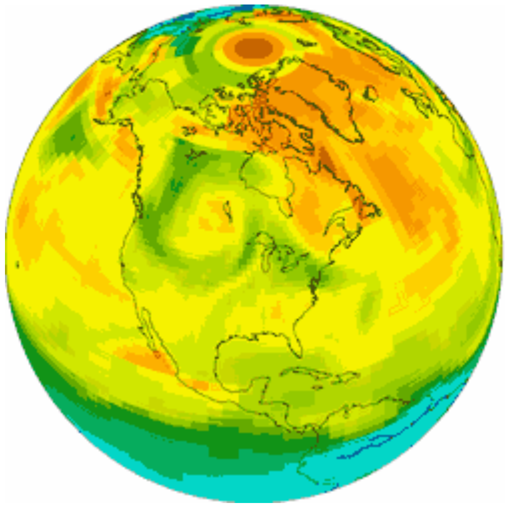
C flows from the atmosphere to the forest and back



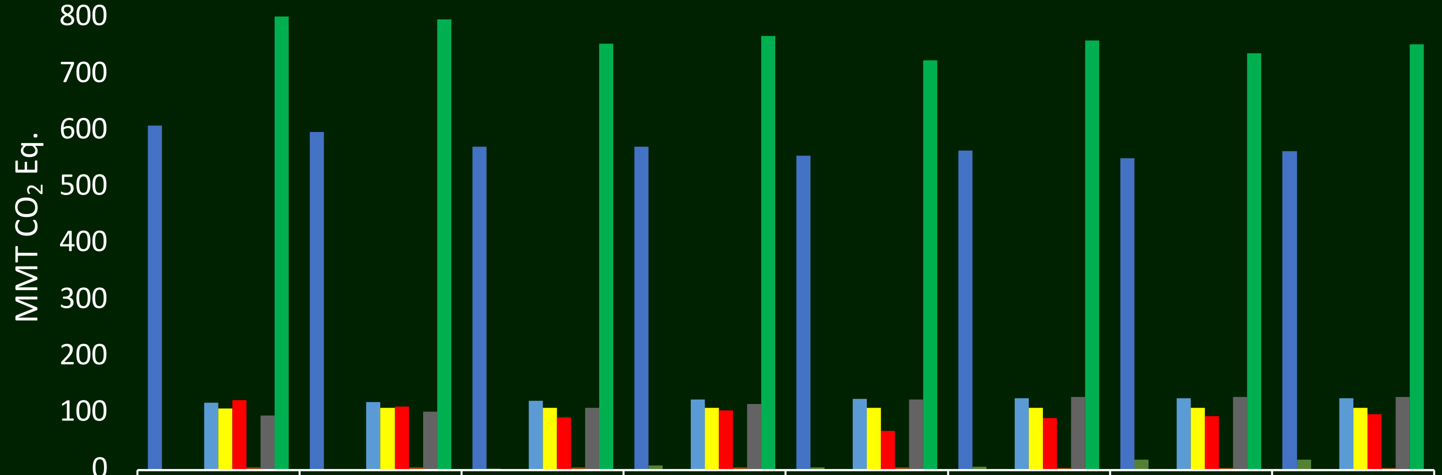
Adapted from Ryan and Law 2005.



CarbonTracker CO2 weather for June-July, 2008. Warm colors show high atmospheric CO2 concentrations, and cool colors show low concentrations. As the summer growing season takes hold, photosynthesis by forests and crops draws concentrations of CO2 down, opposing the general increase from fossil fuel burning. The resulting high- and low-CO2 air masses are then moved around by weather systems to form the patterns shown here.

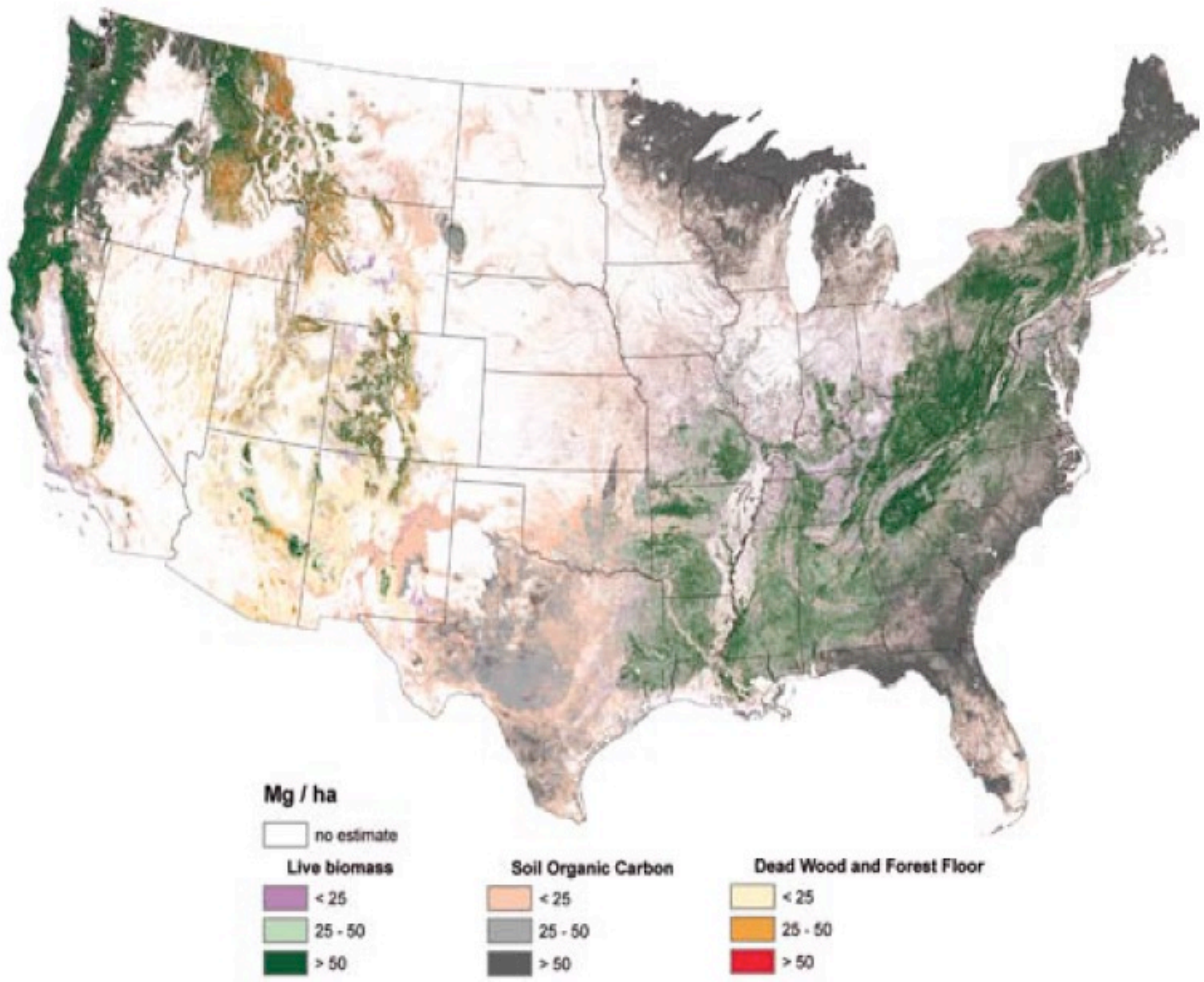
Source: NOAA- Earth System Research Laboratory Global Monitoring Laboratory. **CarbonTracker CT2019.** https://www.esrl.noaa.gov/gmd/ccgg/carbontracker/ Accessed April 25, 2020

Emissions and removals (net flux) from land use, land-use change, and forestry (MMT CO2Eq.)



	1990	1995	2000	2005	2010	2016	2017	2018
Forest Land	610.1	598.7	572.1	572.6	556.2	565.5	552	564.5
Fire emissions	1.5	0.6	2.9	8.2	4.6	5.6	18.8	18.8
Dioxide N Emissions	0.1	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Non C Emissions from D Soils	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Forest Land changed to NFL	119.1	120.8	122.5	124.4	126	127.4	127.4	127.4
Non Forest Land changed to FL	109.4	109.7	109.9	110.2	110.4	110.6	110.6	110.6
Harvested Wood Pdrs.	123.8	112.2	93.4	106	69.1	92.4	95.7	98.8
Woodlands remaining wood lands	5	4.9	4.8	4.6	4.4	4.1	4	4
Urban Trees in Settlements	96.4	103.3	110.4	117.4	124.6	129.8	129.8	129.8
Total emissions and removals	813.9	797.2	755	768.4	724.7	760.6	737.3	752.9

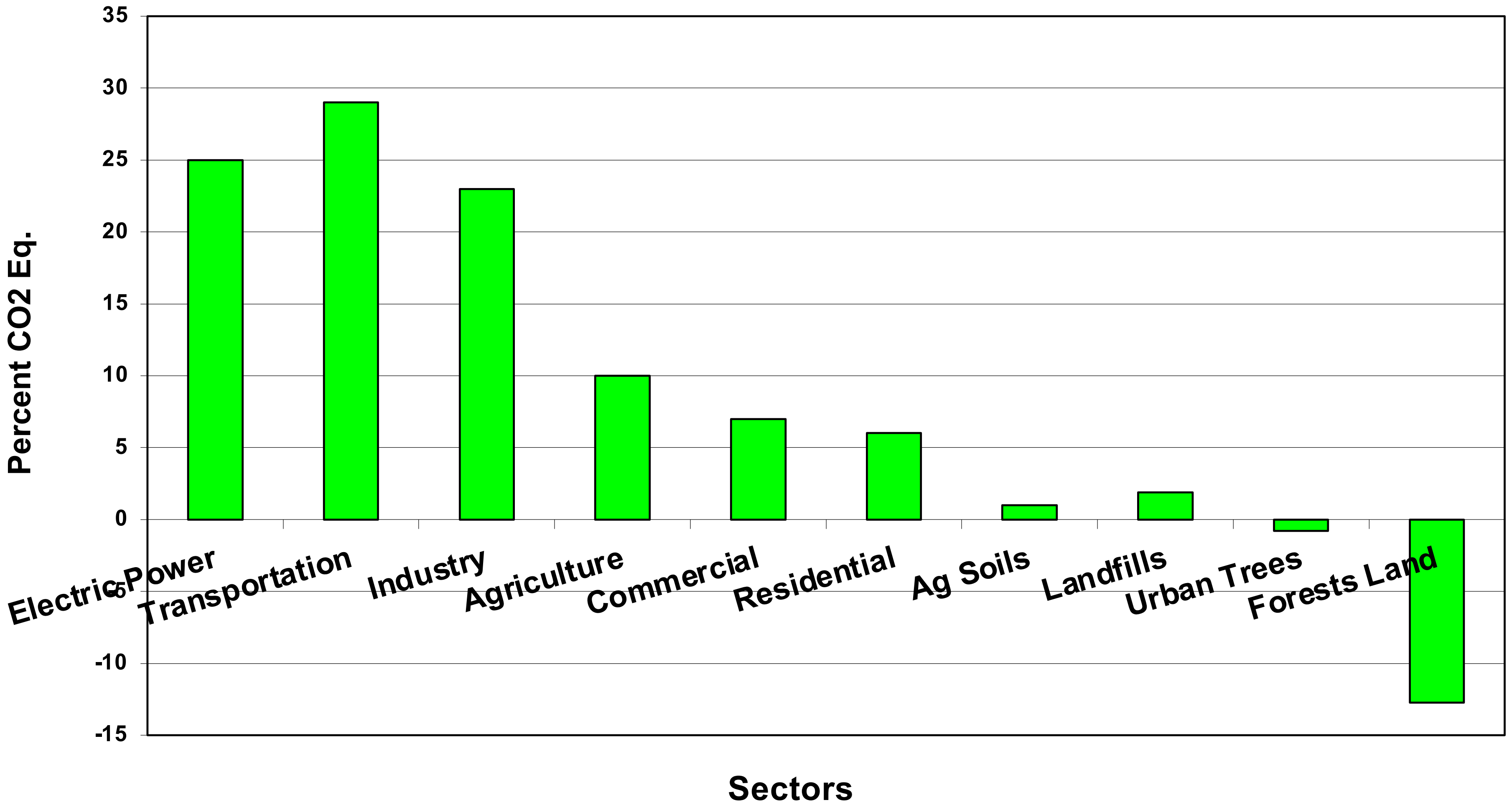
Source: Domke, Grant M.; Walters, Brian F.; Nowak, David J.; Smith, James, E.; Ogle, Stephen M.; Coulston, J.W.; Wirth, T.C. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p. https://doi.org/10.2737/FS-RU-227 .



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

Percent Total US GHG Annual Emissions by Sector (2019)



Note: Negative numbers denote sequestration; forests, trees and wood products sequester 11% to 14 % US GHG emissions annually

Source: https://www.epa.gov/sites/production/files/2019-04/documents/2019_fast_facts_508_0.pdf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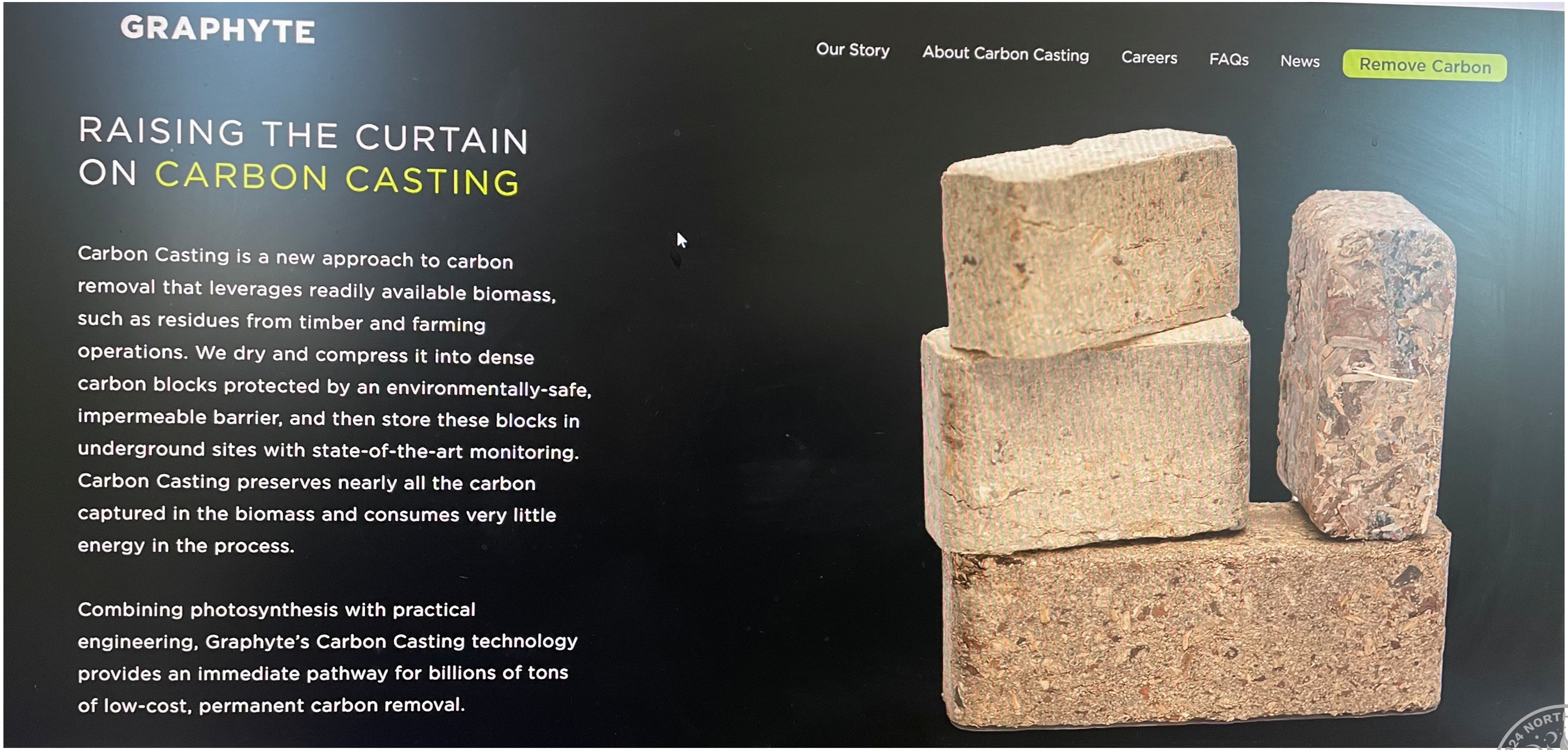
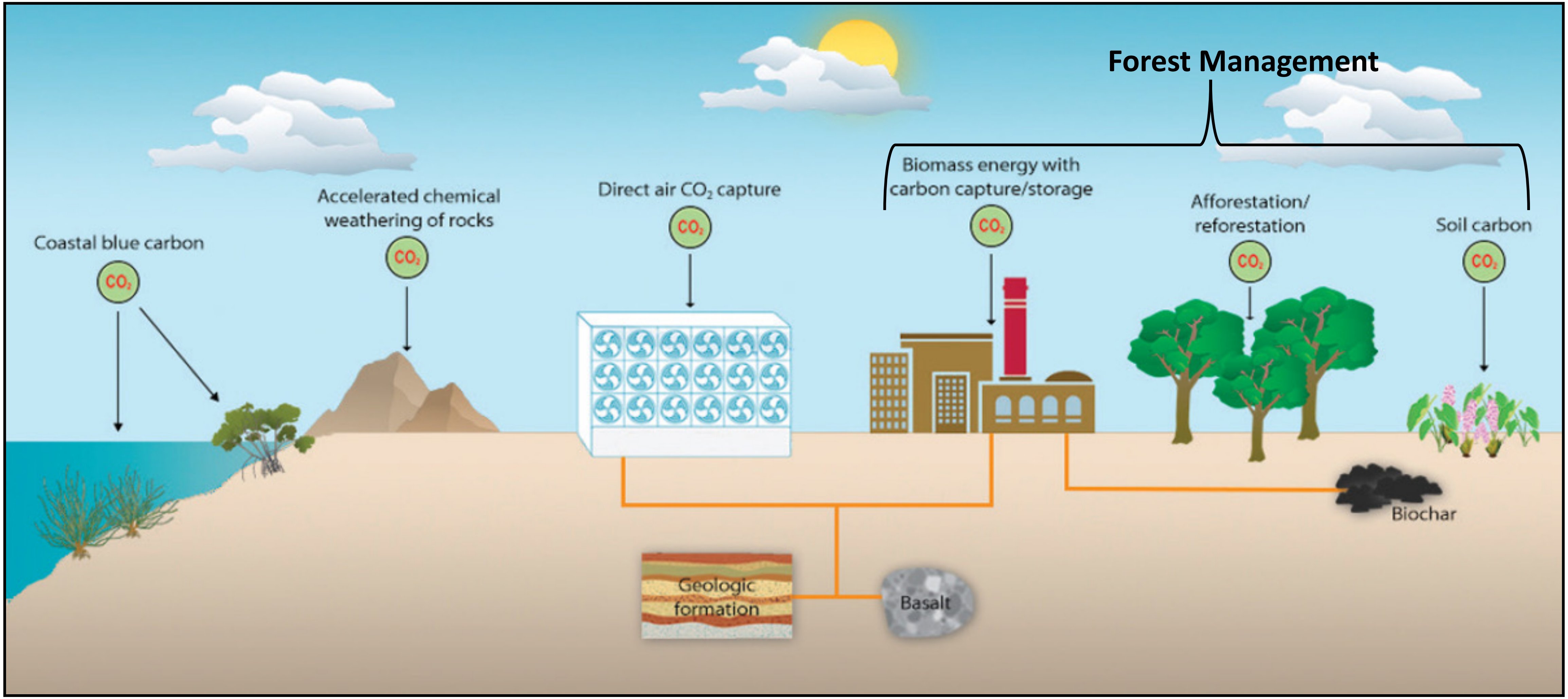


Source: https://www.graphyte.com/



Carbon Negative Emissions Technologies

SOURCE: Le Quéré et al., 2018.National Academies of Sciences, Engineering, and Medicine. 2019. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259.

Forest Management

- There are also forest management technologies to increase carbon sequestration.
- Forests are estimated to cover 4.5 billion ha and equal approximately 31 % of the earth's total land area [31 - 33].
- Forest vegetation accounts for 92% of all terrestrial biomass globally, C stocks are estimated at 662 Gt [36].
- In The US improved forest management can increase C sequestration from 0.03 to 1.6 Gt/yr., and afforestation and reforestation efforts can increase C sequestration in a range of 0.001 to 2.25 Gt/yr. CO_2 [42],
- Globally afforestation, with reduced deforestation and forest management vary from 1.9 to 5.5 Gt CO_2e sequestered per year in 2040 [59].
- Globally, 3 to 5 million km^2 per year are affected by landscape fires which emit 2.2 Pg/yr. C to the atmosphere. However, a significant portion of the burned biomass remains as standing dead or on the soil surface as pyrogenic carbon.
- Over time, pyrogenic C accumulates in soils contributing to C sequestration; which has been estimated to be 12 % of the total C emissions from landscape fires in the world [80].
- Globally, soils store two to three times as much C in organic form as C in the atmosphere, and soil stocks exceed those in plants in most climatic regions [46].
- larger global impacts of the harvested wood products with an annual potential of 2.8 Pg/yr. of C storage [83].

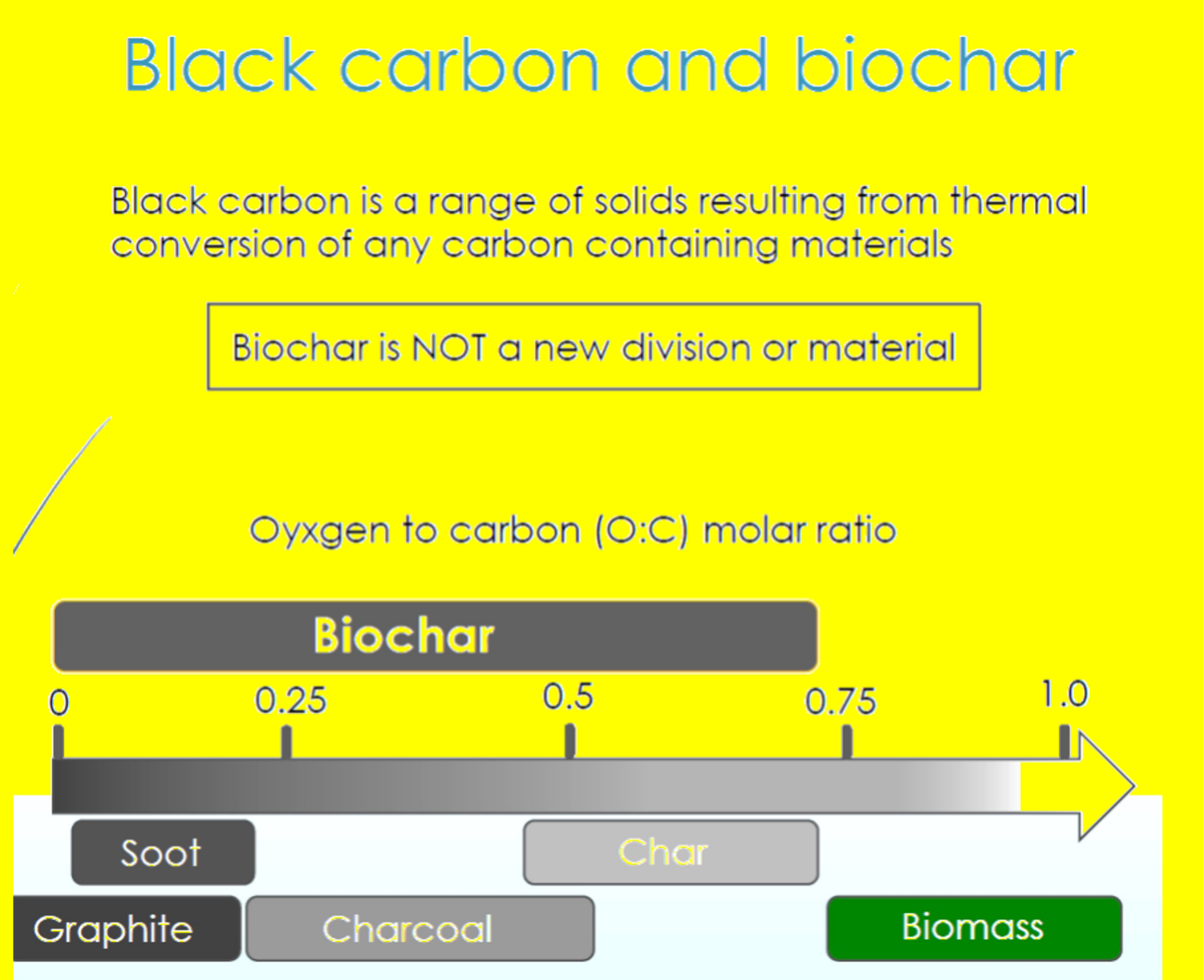
Carbon Allotropes

Source:
More, B.R, and Bokros, C.J. 2006. Biomaterials: Carbon. Encyclopedia of Medical Devices and Instrumentation, 2006. https://doi.org/10.1002/0471732877.emd023

They are different crystalline forms of the same element in the periodic table

- **Diamond**
- **Graphite**
- **Amorphous Carbon**

It is a variety of carbon atoms in a non-crystalline, irregular, glassy state, not held in a crystalline macrostructure. Examples are soot, charcoal and activated carbon.



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

The Carbon Family

	Charcoal	Biochar	Activated Carbon
Feedstock	Hardwood, sawdust + Binding Agents	Ag, forestry & other organic materials/waste	Coconut shells, peat, coal, petroleum pitch
Common Uses	Fuel (Cooking)	Soil Amendment Remediation Filtration Binding Agent (livestock)	Filtration Odor Control Remediation Binding Agent (humans)
Relevant Qualities	Burnability Low smoke	Adsorption/Porosity CEC Sequestration	Adsorption
Cost	$ - $$	$$	$$$
Production	Slow Pyrolysis; Kiln	Slow Pyrolysis; Kiln; Gasification	Pyrolyzed at 600 – 900C + activated at 250C OR Chemically impregnated & cooked @ 450 – 900C
Carbon Footprint	Carbon Neutral: May lead to Deforestation	Carbon Negative (in many situations) ★	Carbon Positive

Source: http://fingerlakesbiochar.com/the-b-word/what-is-biochar/

The Importance of Biochar in Carbon Sequestration to mitigate Climate Change

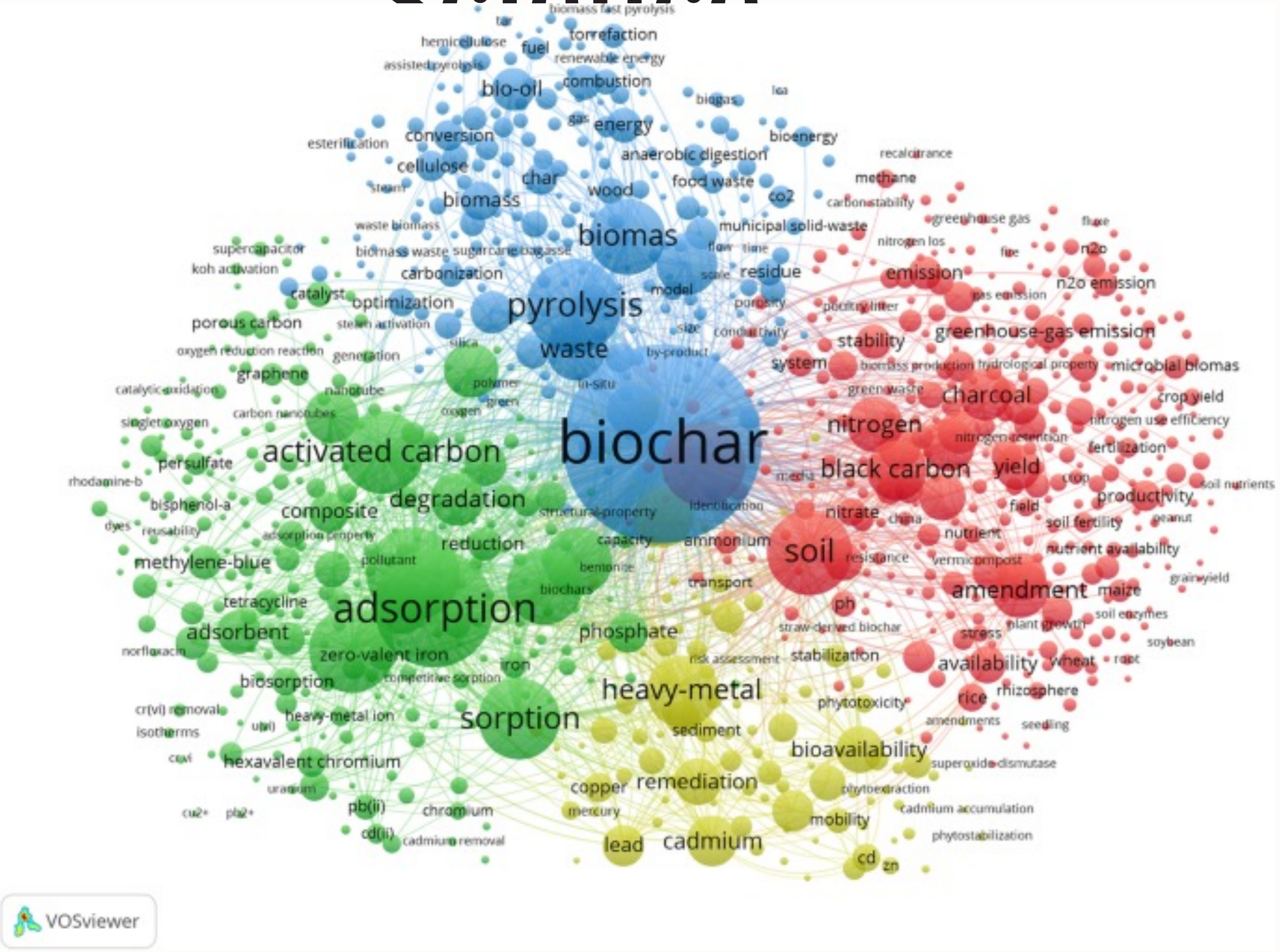
- Lehmann, et., al., (2006) their global analysis indicated that up to 12% of the total anthropogenic C emissions by land use change (0.21 Pg C) can be off-set annually in soil, if slash-and-burn is replaced by slash-and-char.

- 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 produces biochar as 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}).

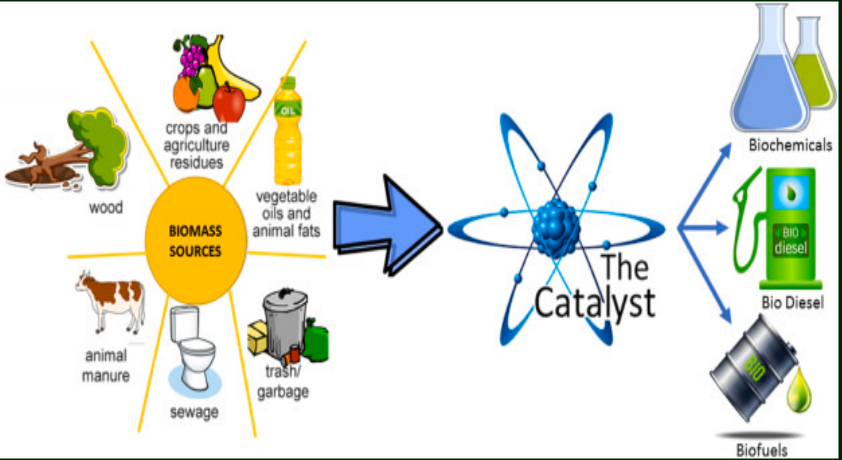
Lehmann, J., Gaunt, J., and Rondon, M. 2006. Bio-char sequestration in terrestrial ecosystems: a review. Mitigation and Adaptation Strategies for Global Change (2006) 11: 403–427. DOI: 10.1007/s11027-005-9006-5

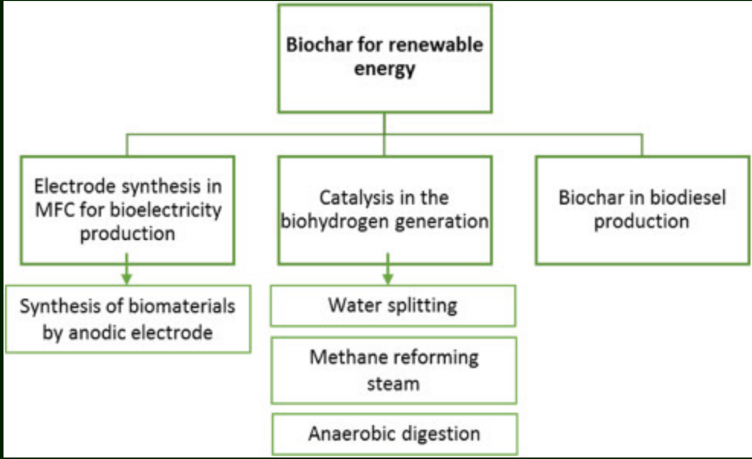
Research focus according to the Web of Science

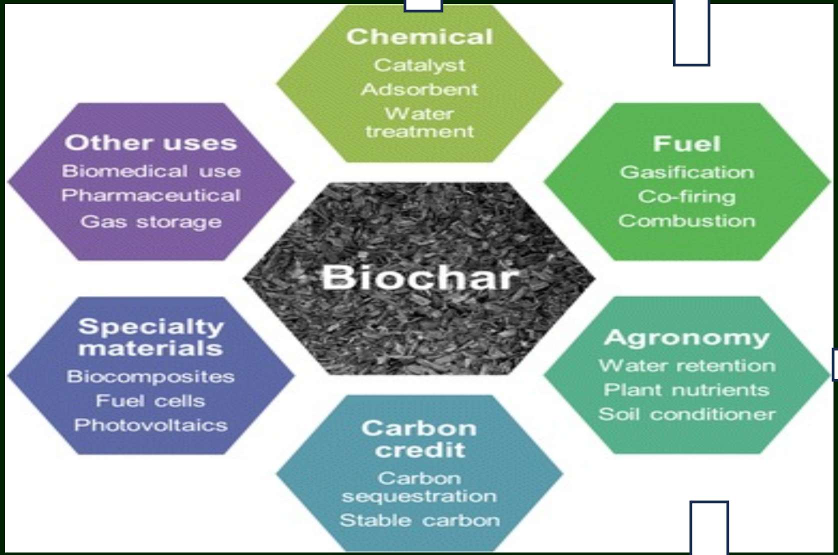


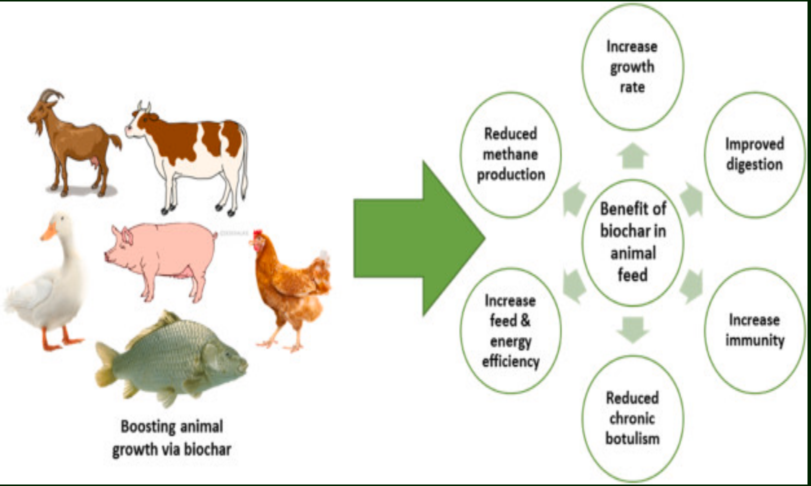
Source: Yang, T., Zhang, Z., Zhu, W. *et al.* Quantitative analysis of the current status and research trends of biochar research - A scientific bibliometric analysis based on global research achievements from 2003 to 2023. *Environ Sci Pollut Res* **30**, 83071–83092 (2023). https://doi.org/10.1007/s11356-023-27992-1

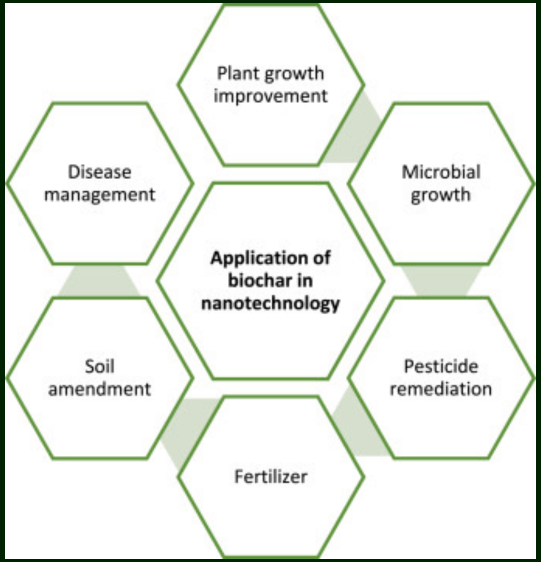
Biochar uses











Source: Nanda, S., Dalai, A.K., Berruti, F. *et al.* Biochar as an Exceptional Bioresource for Energy, Agronomy, Carbon Sequestration, Activated Carbon and Specialty Materials. *Waste Biomass Valor* **7,** 201–235 (2016). https://doi.org/10.1007/s12649-015-9459-z

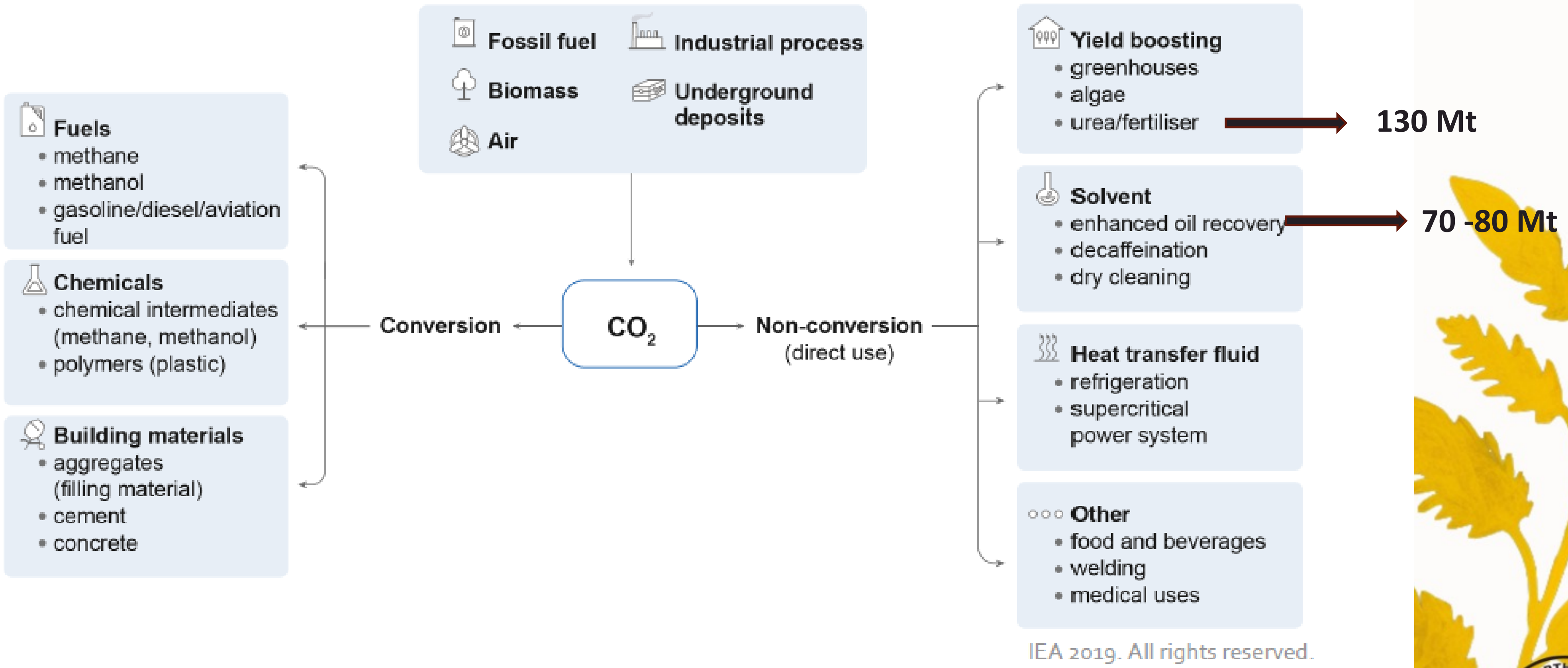
Farah Amalina, Santhana Krishnan, A.W. Zularisam, Mohd Nasrullah. 2023. Recent advancement and applications of biochar technology as a multifunctional component towards sustainable environment. Environmental Development, Volume 46, 2023, 100819. https://doi.org/10.1016/j.envdev.2023.100819

Fig. 1. Schematic diagram of CO_2 capture and utilization cycle.

Lipei Fu, Zhangkun Ren, Wenzhe Si, Qianli Ma, Weiqiu Huang, Kaili Liao, Zhoulan Huang, Yu Wang, Junhua Li, Peng Xu, Research progress on CO2 capture and utilization technology, Journal of CO2 Utilization, Volume 66, 2022,102260. https://doi.org/10.1016/j.jcou.2022.102260

Simplied classification of CO_2 use pathways

(230 million tons/yr. used globally)



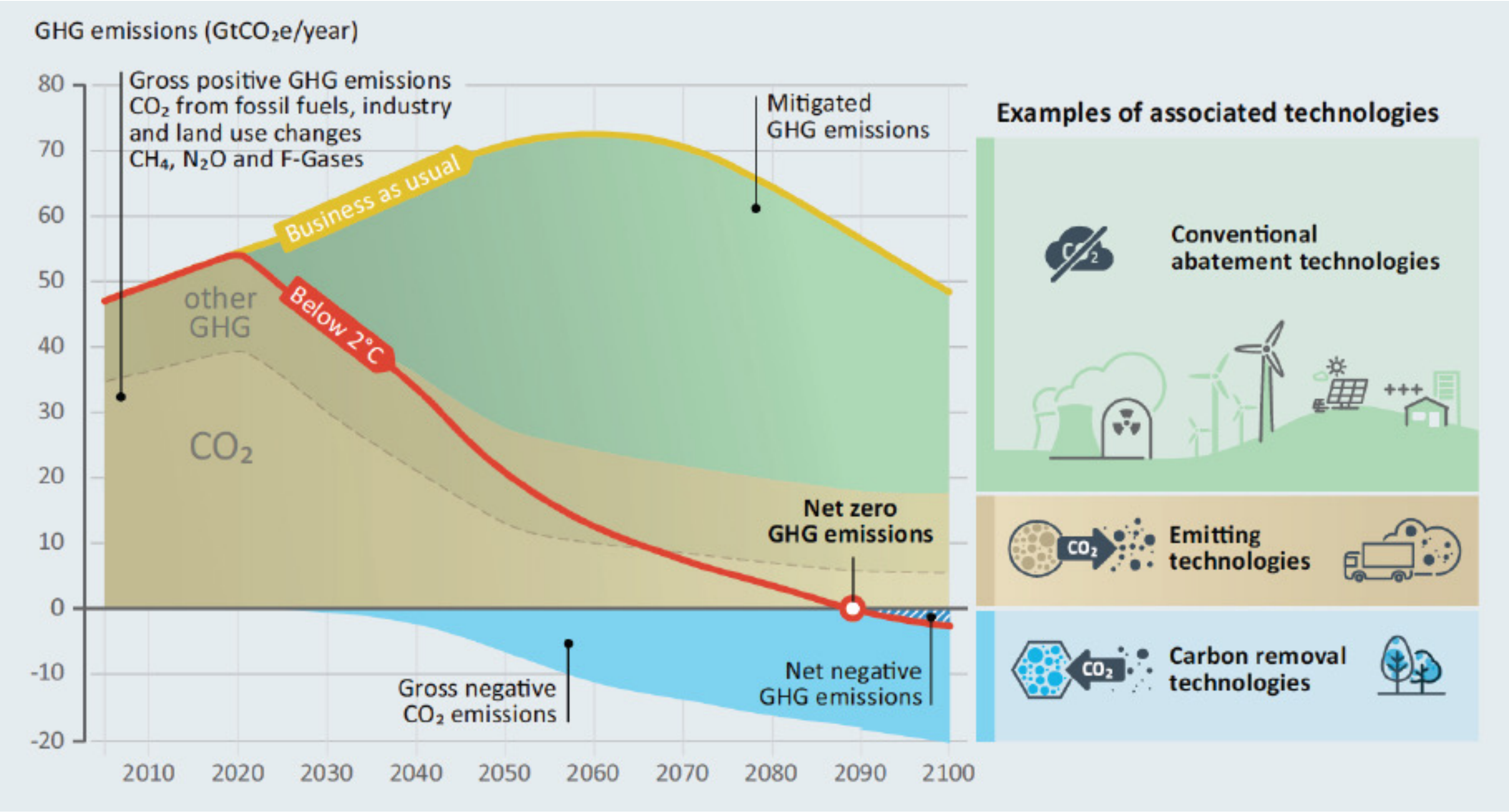
Source: International Energy Agency. 2019. Putting CO2 to Use - Creating value from emissions. https://www.iea.org/reports/putting-co2-to-use

C utilization considerations

- C sequestration, CDR removal, CCS storage and CCU utilization are not the same. All of them potentially help to decrease atmospheric C.
- CO_2 utilization is not the same as CO_2 avoided (benefits to CC have to be assessed with LCA). Some utilization pathways still could release CO_2. Some can achieve CDR. Some CCS can contribute to CC mitigation, when
- CO_2 would have to be sourced from biomass or the air to achieve climate benefits.
- CO_2-derived products that involve permanent carbon retention, such as building materials, can offer larger emissions reductions than products that ultimately release CO_2 to the atmosphere. Biochar should be considered in this category.
- CO_2 utilization is not expected to deliver emissions reductions on the same scale as carbon capture and storage (CCS).

Source: International Energy Agency. 2019. Putting CO2 to Use - Creating value from emissions. https://www.iea.org/reports/putting-co2-to-use
Hepburn, C., Adlen, E., Beddington, J. *et al.* The technological and economic prospects for CO_2 utilization and removal. *Nature* 575, 87–97 (2019). https://doi.org/10.1038/s41586-019-1681-6

Scenario of the role of negative emissions technologies in reaching net zero emissions.



Source: National Academies of Sciences, Engineering, and Medicine 2019. Negative Emissions Technologies and Reliable Sequestration: A Research Agenda. Washington, DC: The National Academies Press. https://doi.org/10.17226/25259 .

Fig. 3. The collaboration network of countries and institutions. Nodes represent countries and institutions. The size of a node is proportional to the amount of papers produced by the country or institution. The links represent the collaborative relationship between different countries and institutions. The color of the rings and links corresponds to the year. The purple rings indicate high centrality. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Huang, L., Zhou, Mi., Lv, J., and Chen, K. 2020. Trends in global research in forest carbon sequestration: A bibliometric analysis. Journal of Cleaner Production 252 (2020) 119908. https://doi.org/10.1016/j.jclepro.2019.119908

THANK YOU