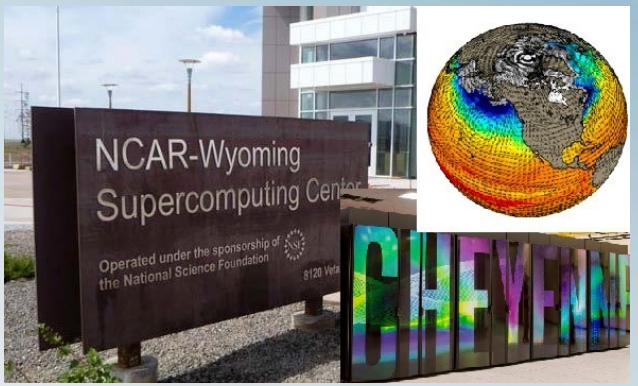


Land-based CDR and Reliable Sequestration

Peter Lawrence

Contributions from: Stephanie Roe, Sabine Fuss, Dave Lawrence, Yanyan Chen, James King, and many others

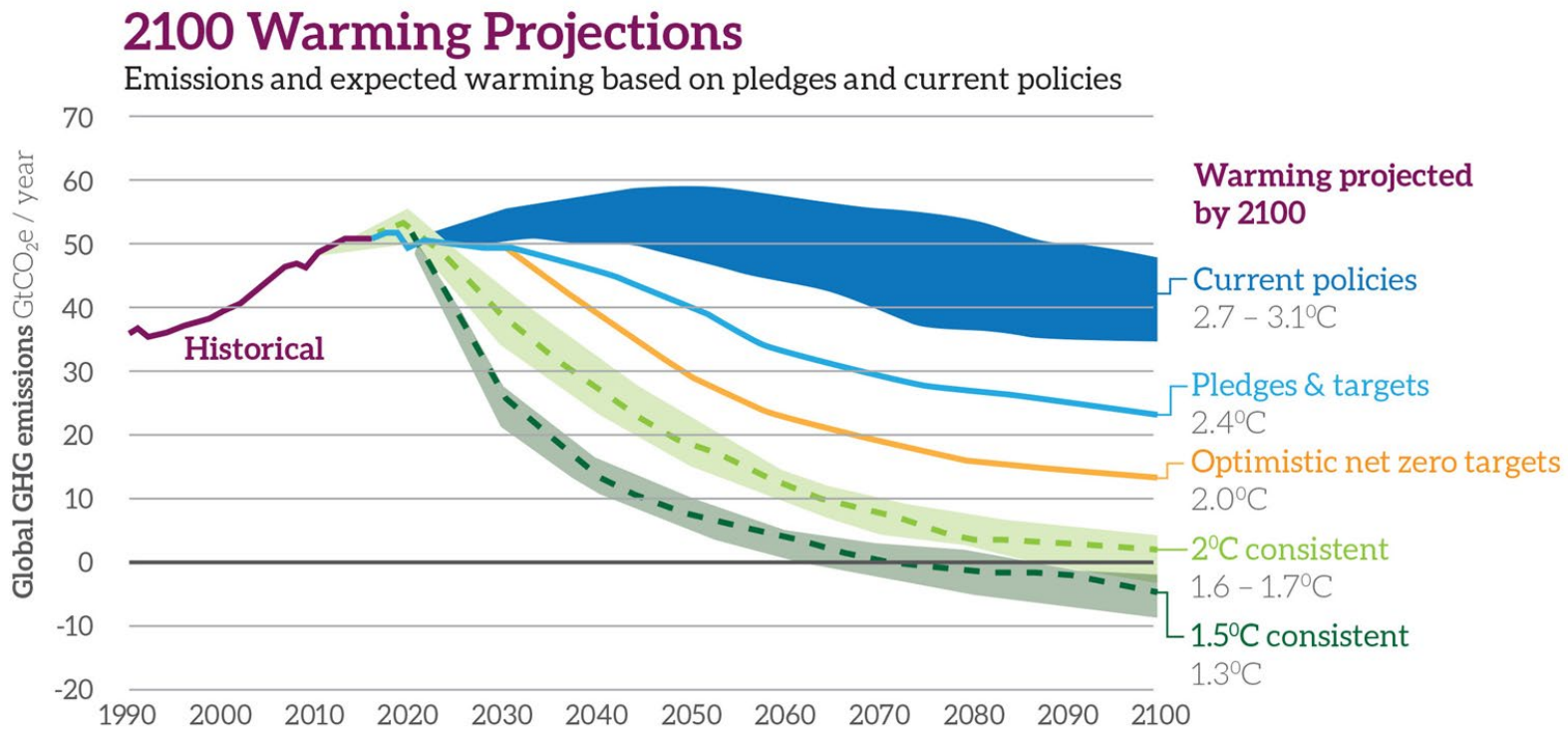
NCAR

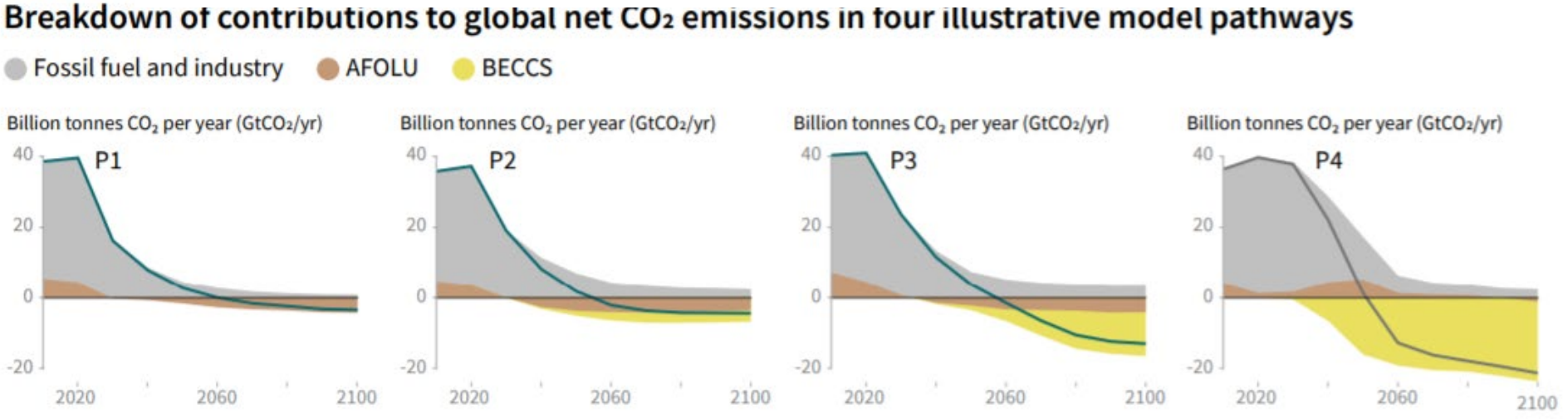
National Academies CI Workshop- June 2023

NSF

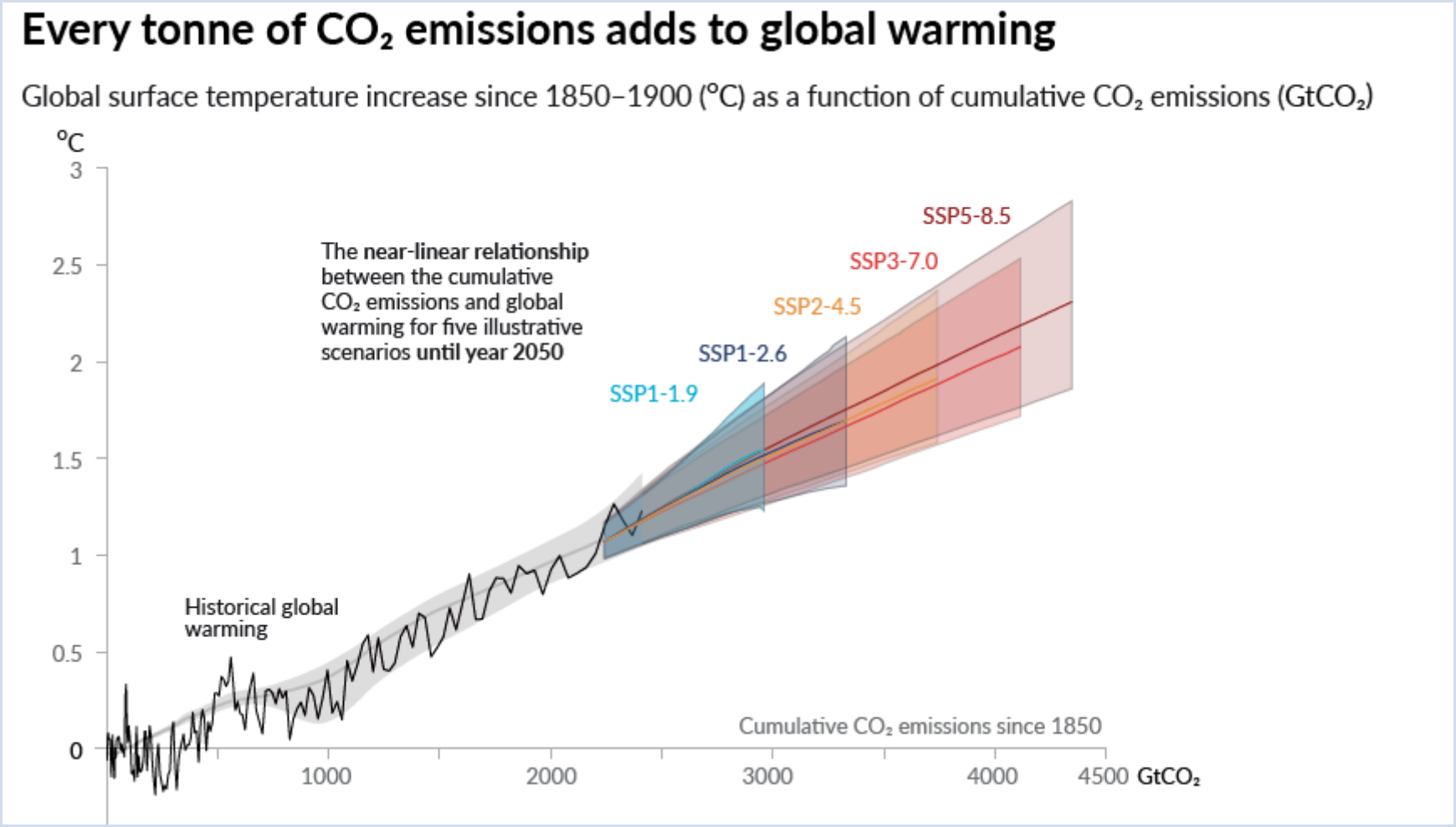
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

COP 27 Paris Targets – IPCC SR 1.5C – Emissions and CDR





Transient Climate Response to Emissions



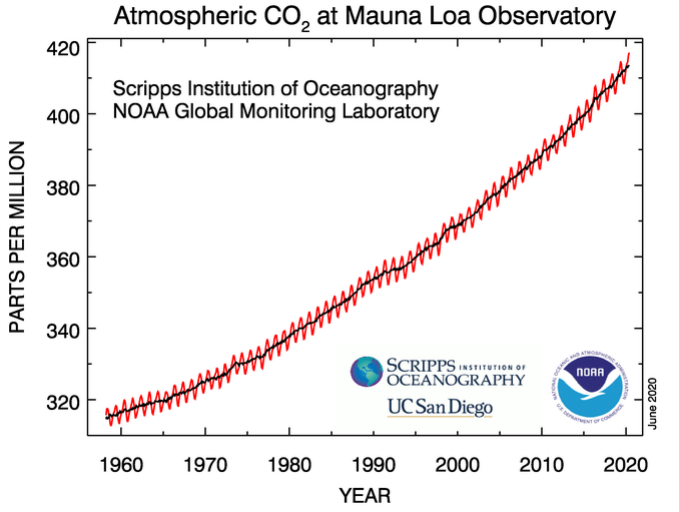
IPCC AR6

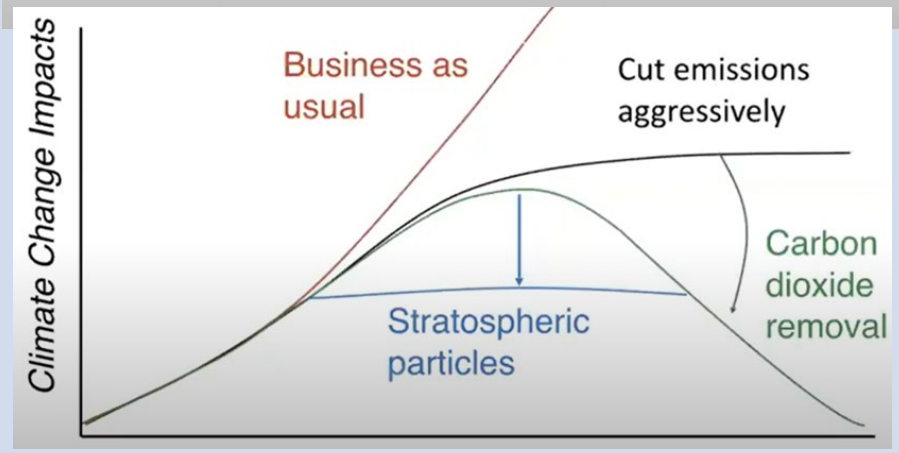
To change from a higher to a lower SSP without changing emissions takes around 350 GtCO2 or 100 PgC of CDR

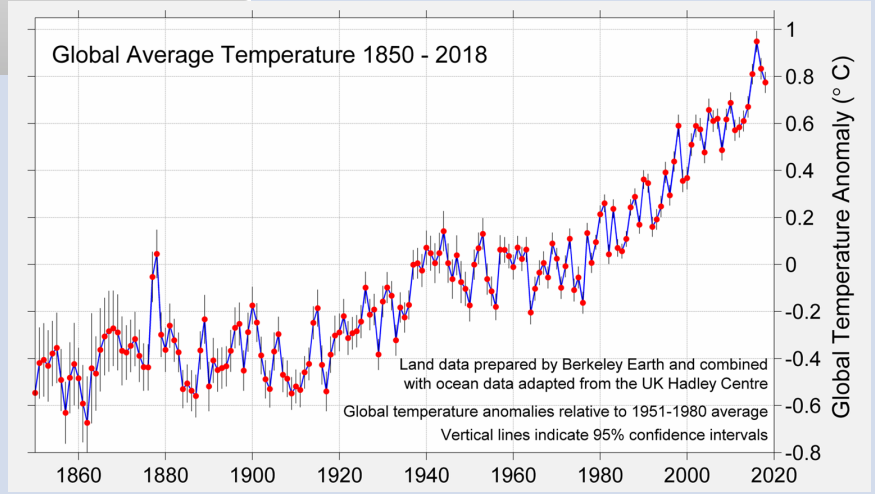
United Nations Framework Convention on Climate Change

UNFCCC (1992)

- Framework Convention calls for enhancing "sinks"—any process, activity, or mechanism that removes a GHG from the atmosphere
- Kyoto Protocol Clean Development Mechanism has promoted A/R offsets (and allows for CCS)
- Paris Agreement calls for "balance between anthropogenic emissions by sources and removals by sinks"
- 2 °C/1.5 °C assumes BECCS (IPCC, SR1.5)
- *But* Paris rulebook provisions on "cooperative mechanisms" (carbon trading) are unfinished, and if/when they are completed (Glasgow COP?) they will exclude CDR
- UNFCCC says nothing about SRM
  - Framed around GHGs, not RF

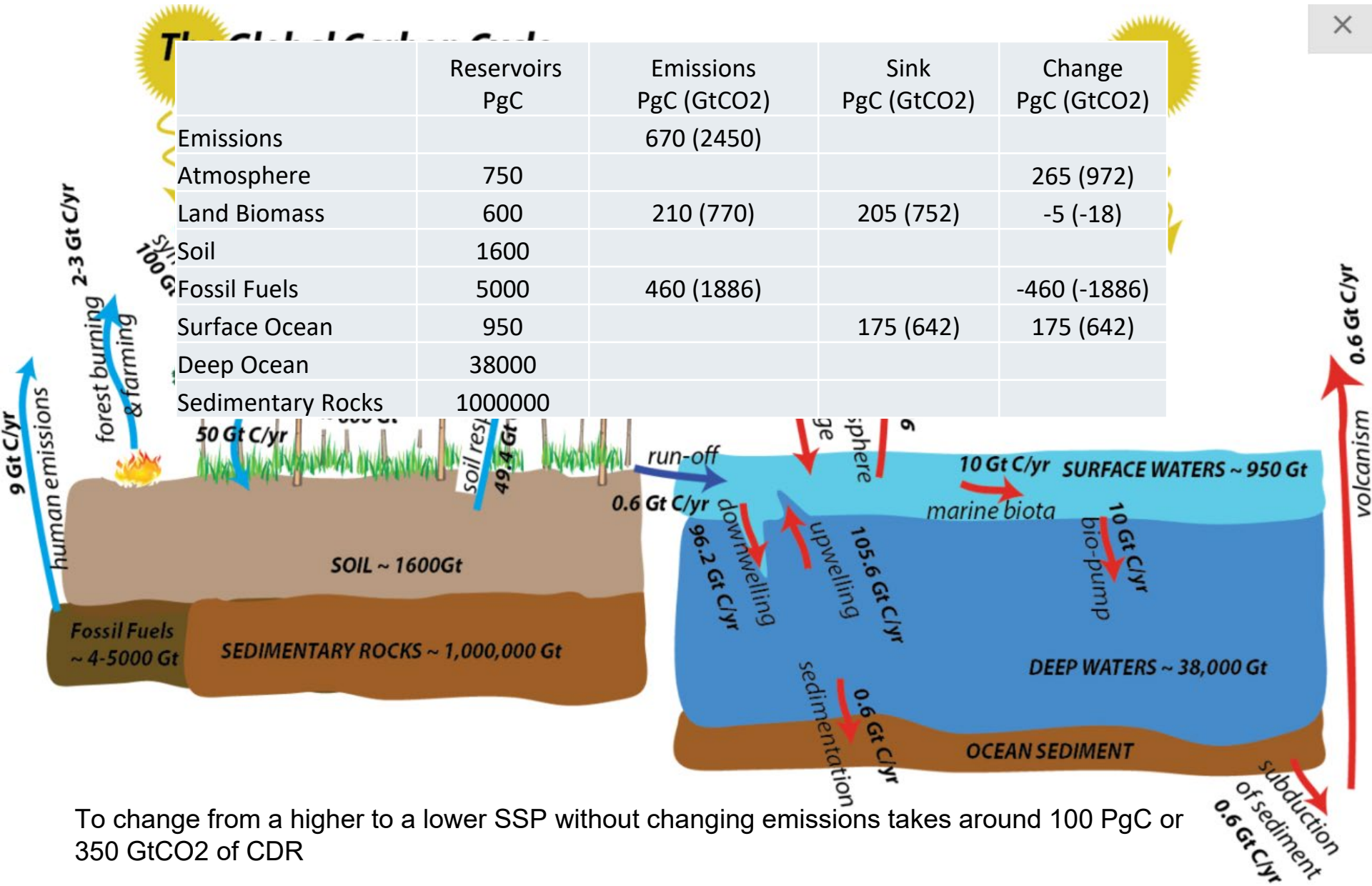






Global Carbon Cycle Reservoirs and Fluxes

	Reservoirs PgC	Emissions PgC (GtCO2)	Sink PgC (GtCO2)	Change PgC (GtCO2)
Emissions		670 (2450)		
Atmosphere	750			265 (972)
Land Biomass	600	210 (770)	205 (752)	-5 (-18)
Soil	1600			
Fossil Fuels	5000	460 (1886)		-460 (-1886)
Surface Ocean	950		175 (642)	175 (642)
Deep Ocean	38000			
Sedimentary Rocks	1000000			



To change from a higher to a lower SSP without changing emissions takes around 100 PgC or 350 GtCO2 of CDR

Land-based CDR activities in the Literature and Media

Restoring Forests Could Help Put a Brake on Global Warming, Study Finds

Timeline: How BECCS became climate change's 'saviour' technology

Are Huge Tree Planting Projects More Hype than Solution?

High-profile programs aimed at planting billions of trees are being launched worldwide. But a growing number of scientists are warning that these massive projects can wreck natural ecosystems, dry up water supplies, damage agriculture, and push people off their land.

Tree planting is not a simple solution

Tree planting must be carefully planned and implemented to achieve desired outcomes

GOV.UK

Government launches new scheme to boost tree-planting

Woodlands and forests will play an important role in the UK's efforts to hit ... By planting more trees and creating new woodland, land managers ...

Nov 4, 2019

Farming could be absorber of carbon by 2050, says report

Veganism and trees could help stop agriculture contributing to global heating, study says

Can regenerative agriculture reverse climate change? Big Food is banking on it.

Regenerative agriculture works to draw carbon out of the atmosphere and into the soil, but there's an ongoing debate on how much carbon can be stored there and for how long.

Soil Carbon: The Secret Weapon to Battle Climate Change?

Tree planting 'has mind-blowing potential' to tackle climate crisis

Research shows a trillion trees could be planted to capture huge amount of carbon dioxide

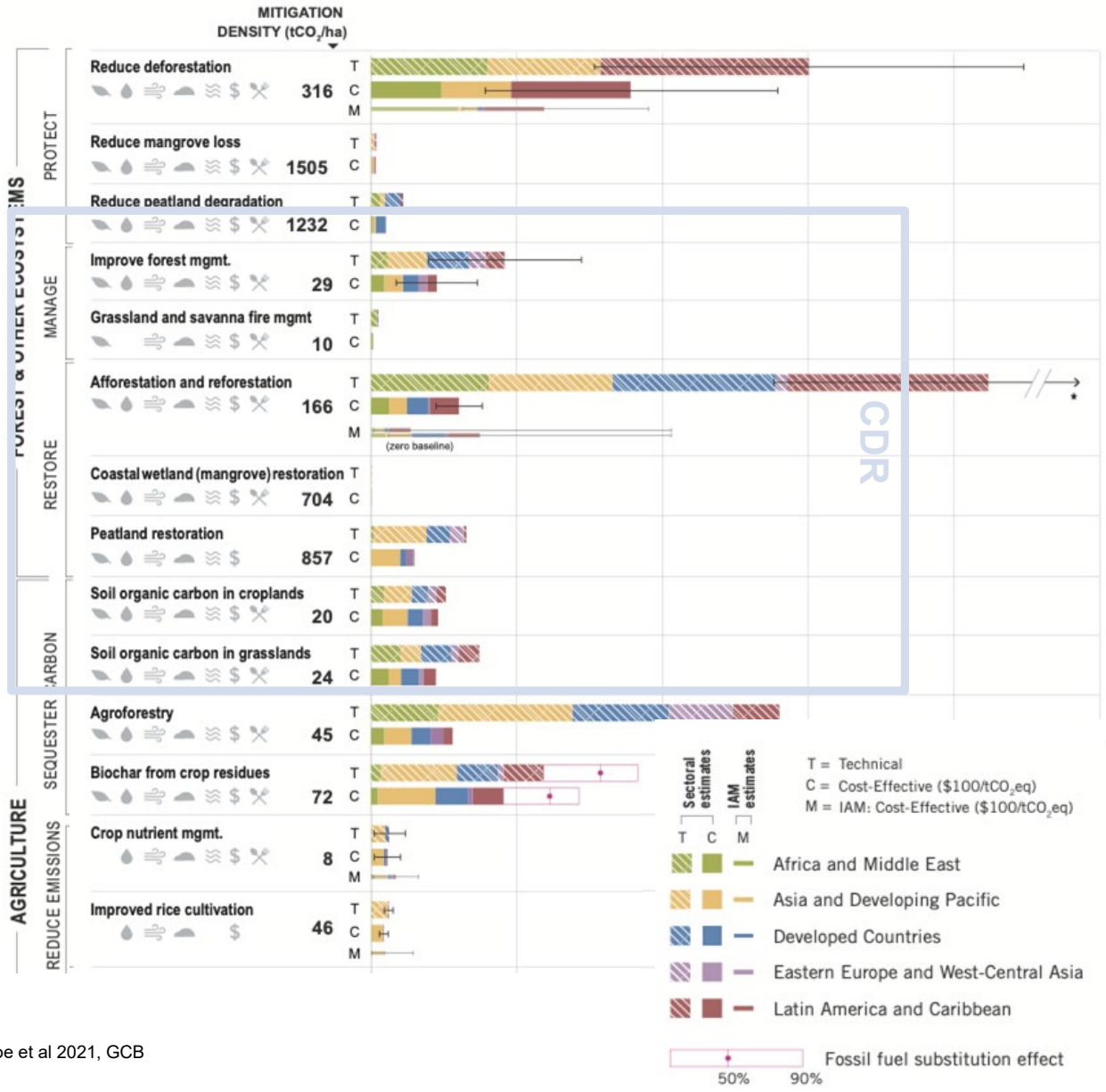
"A Trillion Trees" is a great idea—that could become a dangerous climate distraction

Reforestation is critical for lots of reasons, but it's no substitute for cutting emissions.

Carbon farming is the hot (and overhyped) tool to fight climate change

Using farms to capture and store more carbon in soil is becoming trendy, but the science is still not settled on how much it can help to address climate change.

Land-based CDR activities and Potentials Roe et al. 2021 GCB



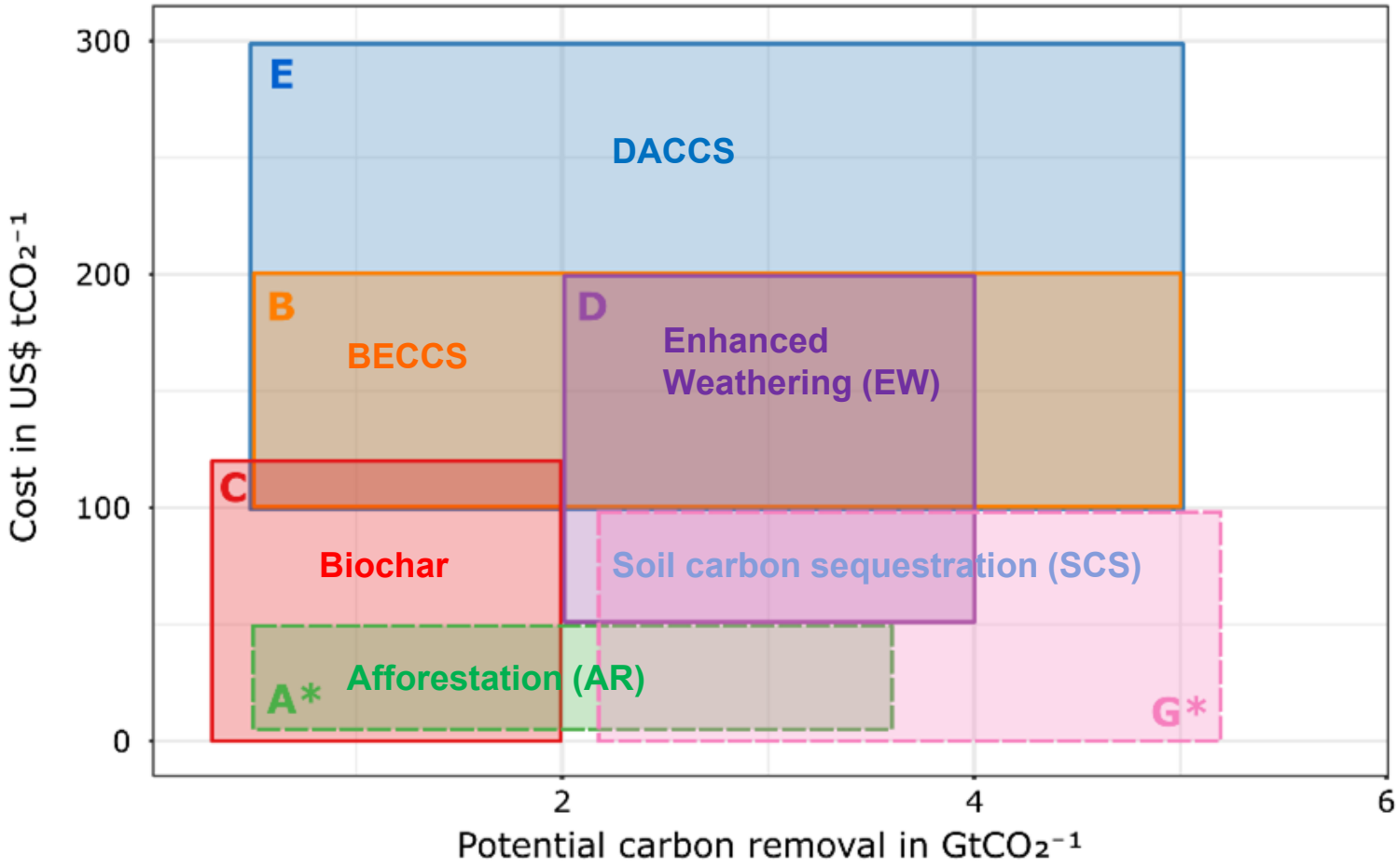
Roe et al 2021, GCB

Highest cost-effective potential:

- Biochar (1.8 Gt yr-1)
- Re/Afforestation (1.2 Gt yr-1)
- Agroforestry (1.1 Gt yr-1)
- Soil carbon croplands (0.92 Gt yr-1)
- Soil carbon grasslands (0.9 Gt yr-1)
- Forest management (0.9 Gt yr-1)
- Peatland restoration (0.6 Gt yr-1)
- Coastal wetland restore (0.3 Gt yr-1)

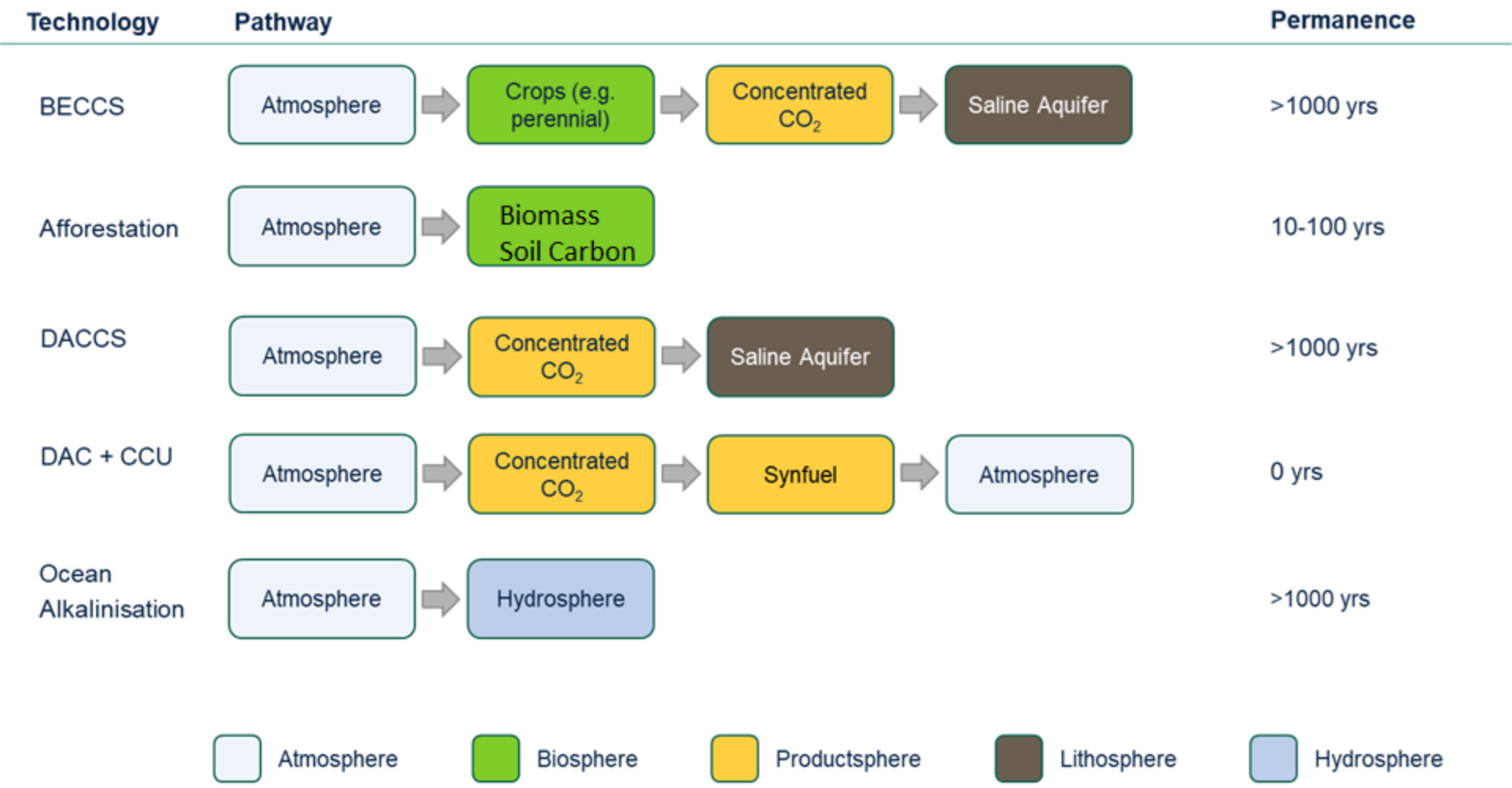
CDR Relative Costs versus Removal Potential

2050 costs and potentials of removal options



Source: Fuss et al. *ERL* 2018

CDR Permanence and Process Complexity



BECCS (Bioenergy with Carbon Capture and Storage) DACCS (Direct Air Carbon Capture and Storage) CCU (Utilization)

Source: Courtesy of Steve Smith, translated from Fuss et al. (2022, in German)

Carbon Dioxide Removal through Re/Afforestation

The carbon dioxide removal potential for large scale Reforestation and Afforestation has been receiving much attention in both the literature and the press.

nature climate change

Letter | Published: 27 May 2019

Potential for low-cost carbon dioxide removal through tropical reforestation

Jonah Busch, Jens Engelmann, Susan C. Cook-Patton, Bronson W. Griscom, Timm Kroeger, Hugh Possingham & Priya Shyamsundar

MENU nature International journal of science Subscribe

NEWS FEATURE · 15 JANUARY 2019

How much can forests fight climate change?

Trees are supposed to slow global warming, but growing evidence suggests they might not always be climate saviours.

Gabriel Popkin

Science Contents News Careers Jou

SHARE REPORT

The global tree restoration potential

Jean-Francois Bastin[1,*], Yelena Finegold[2], Claude Garcia[3,4], Danilo Mollicone[2], Marcelo Rezende[2], Devin Routh[1], Constantin...

+ See all authors and affiliations

Science 05 Jul 2019:
Vol. 365, Issue 6448, pp. 76-79
DOI: 10.1126/science.aax0848

The New York Times

Restoring Forests Could Help Put a Brake on Global Warming, Study Finds

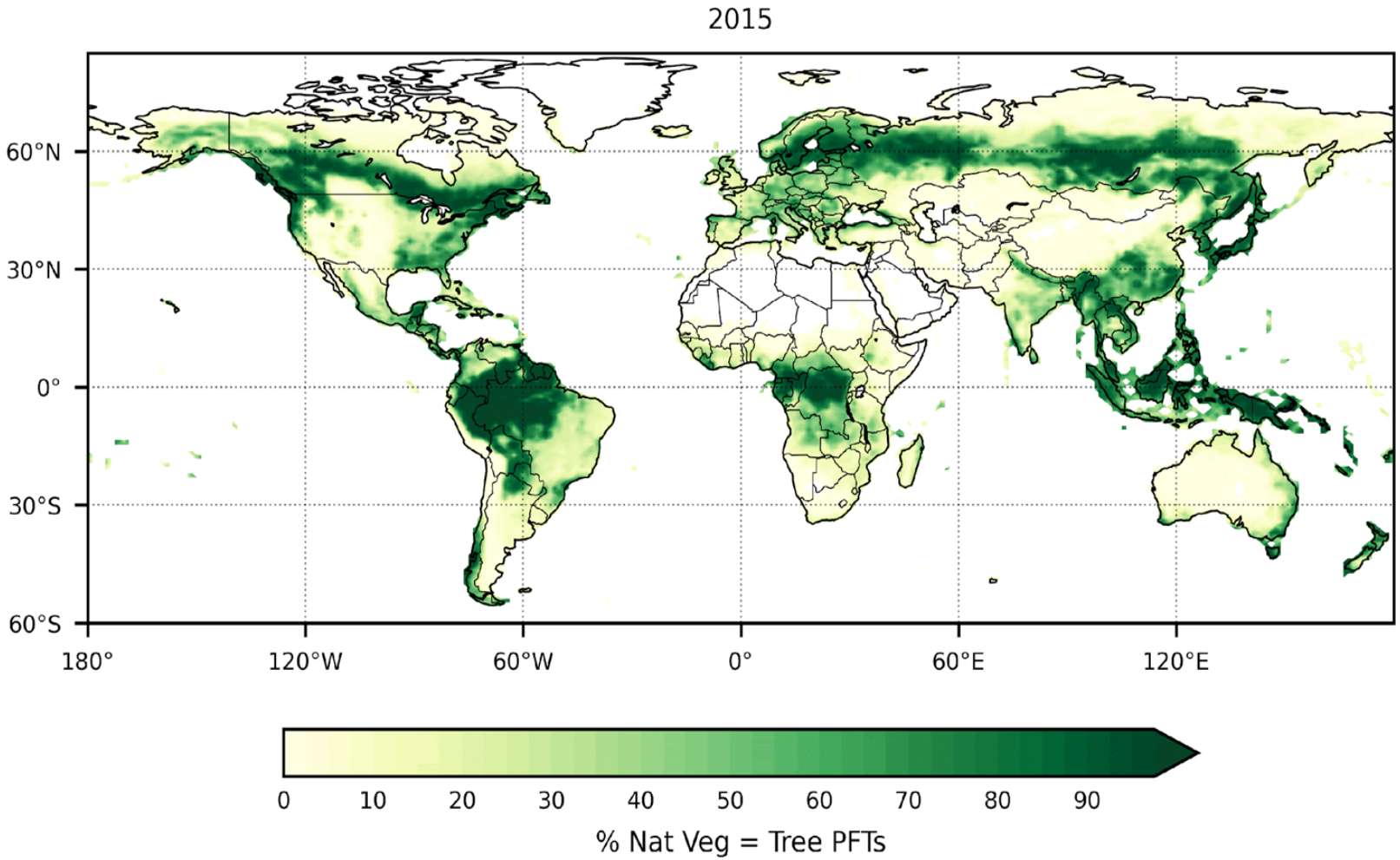
Natural climate solutions

Bronson W. Griscom, Justin Adams, Peter W. Ellis, Richard A. Houghton, Guy Lomax, Daniela A. Miteva, William H. Schlesinger, David Shoch, Juha V. Siikamäki, Pete Smith, Peter Woodbury, Chris Zganjar, Allen Blackman, João Campari, Richard T. Conant, Christopher Delgado, Patricia Elias, Trisha Gopalakrishna, Marisa R. Hamsik, Mario Herr Joseph Kiesecker, Emily Landis, Lars Laestadius, Sara M. Leavitt, Susan Minnemeyer, Stephen Polasky, Peter Potapov, Francis E. Putz, Jonathan Sanderman, Marcel Silvius, Eva Wollenberg, and Joseph Fargione

PNAS October 31, 2017 114 (44) 11645-11650; first published October 16, 2017 https://doi.org/10.1073/pnas.1

Range of results upper end has:
Re/Afforestation of 9 million km²
With 205 PgC additional storage
(Cumulative emissions ~500 PgC)

Maximum Afforestation within Climate and Land Use

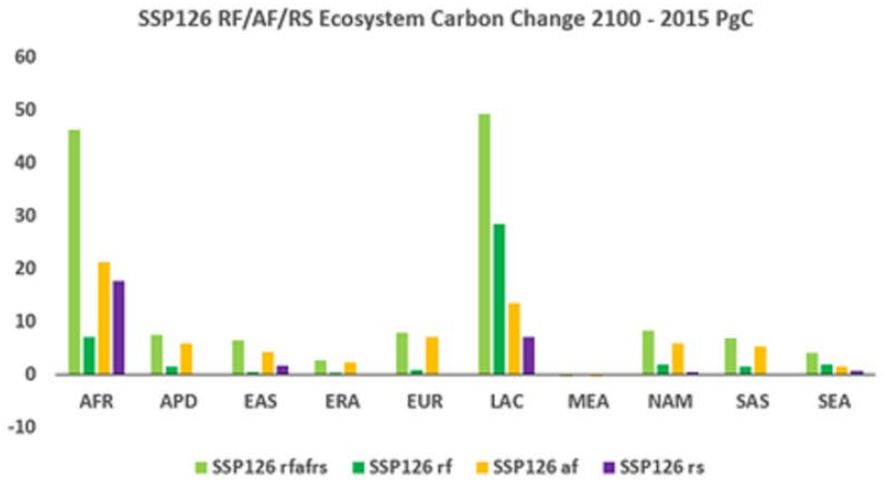


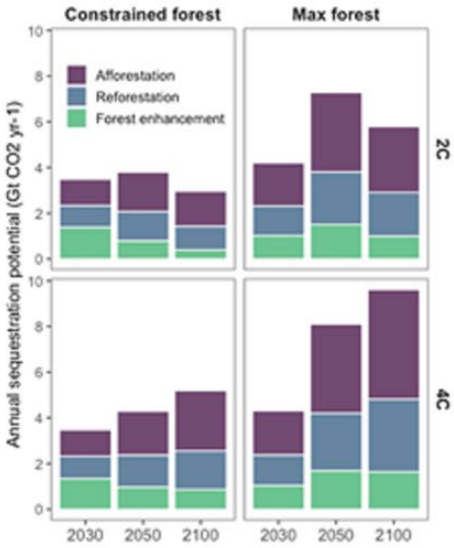
Generated Maximum Plausible Reforestation, Afforestation and Restoration Scenarios compared with CMIP6 Baseline Scenarios 2015 – 2100 at 0.25 degrees resolution with agricultural and climate limits:

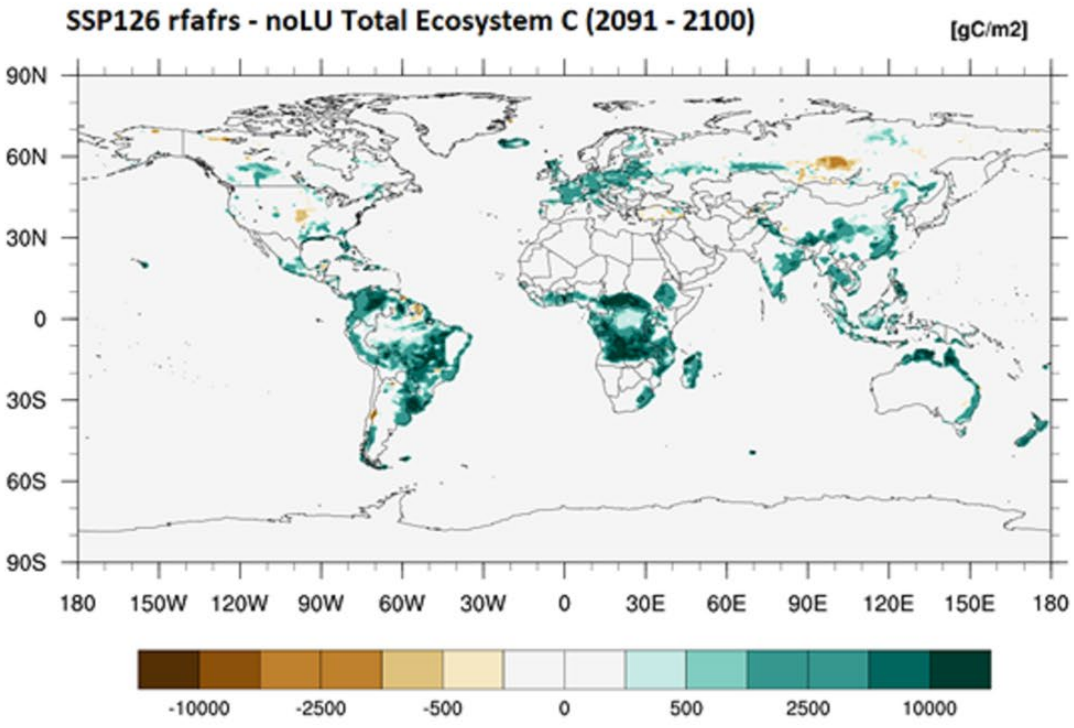
- **Global Reforestation** 2.3m km2 **Afforestation** 5.5m km2 **Restoration** 1.5m km2 **Total** 9.4m km2

Thanks to James King for Animation

CLM5 RCP 2.6 Re/Afforestation – Total Eco Carbon 139 PgC







Restoration 44 PgC
Afforestation 67 PgC
Restoration 28 PgC **Total** 139 PgC

South America has large reforestation smaller afforestation and restoration

Central Africa has large afforestation and restoration and smaller reforestation due to agricultural limits

Tropical Forests have large carbon uptake with increased evapotranspiration and cooling

Mid and High Latitude Forest result in low carbon uptake with lower albedo and warming

CESM Accounting for Land Cover Change Impacts in BECCS

The carbon dioxide removal potential for large scale Bioenergy with Carbon Capture and Storage (BECCS).

Science Contents News Careers Journals

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REVIEW

Cellulosic biofuel contributions to a sustainable energy future: Choices and outcomes

G. Philip Robertson[1,2,3,*], Stephen K. Hamilton[1,3,4], Bradford L. Barham[5,6], Bruce E. Dale[3,7], R. Cesar Izaurralde[3,8,9], Randall ...

+ See all authors and affiliations

Science 30 Jun 2017:

ELSEVIER

Journal of Integrative Agriculture

Volume 16, Issue 6, June 2017, Pages 1197-1210

ELSEVIER

Global Environmental Change

Volume 42, January 2017, Pages 153-168

REVIEW

Modeling the biomass of energy crops: Descriptions, strengths and prospective

Rui JIANG [a, b], Tong-tong WANG [a], Jin SHAO [c], Sheng GUO [a], Wei ZHU [a], Ya-jun YU [a], Ryusuke HATANO [e]

The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview

Keywan Riahi [a], Detlef P. van Vuuren [b], Elmar Kriegler [c], Jae Edmonds [d], Brian C. O'Neill [e], Shinichiro Fujimori [f],

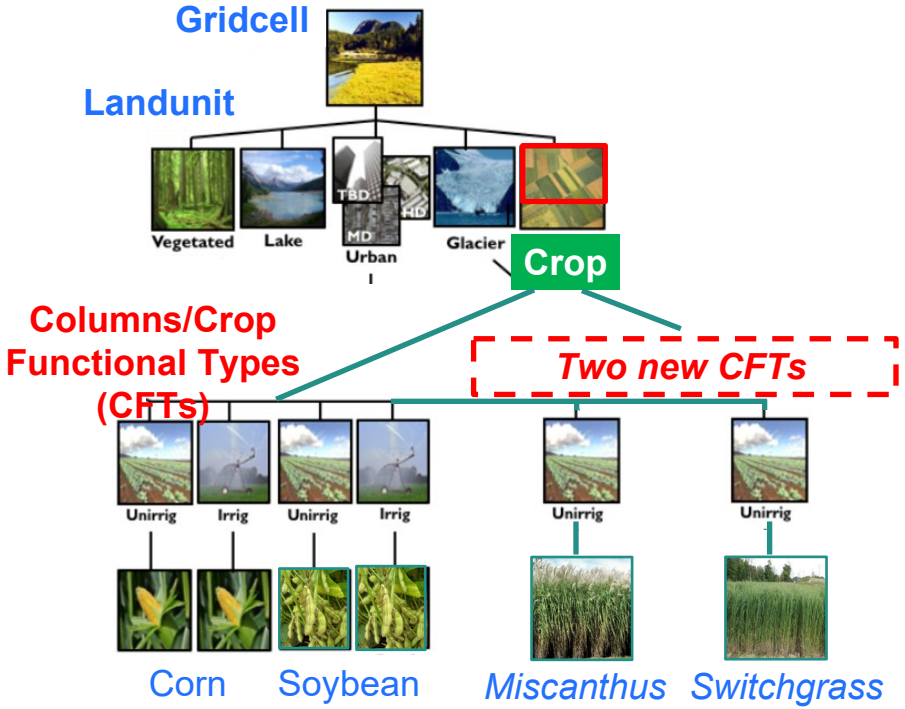
All SSP Mitigation Scenarios use Bioenergy with Carbon Capture and Storage in some form to provide renewable liquid fuels to reduce fossil fuel emissions

Bioenergy crops added to CESM

Traditional crops can be and are used as biofuel feedstocks

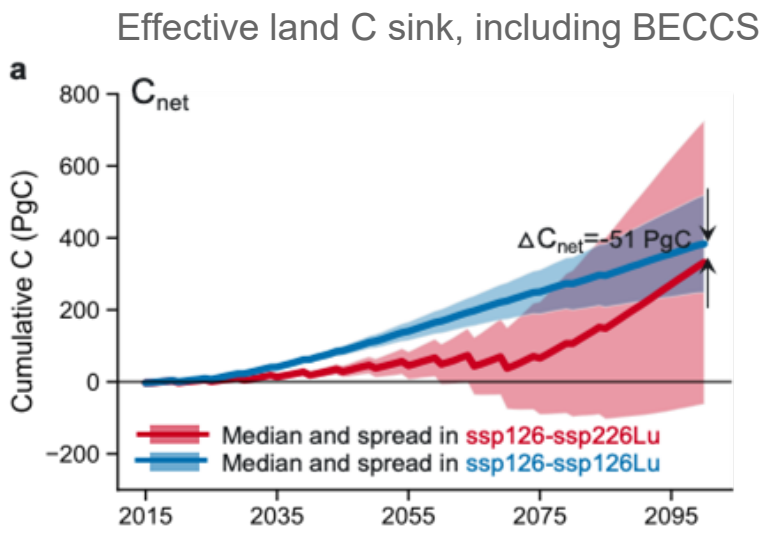
But, perennial grasses such as ***Switchgrass*** **and** ***Miscanthus*** have higher productivity and water use efficiency as well as lower demands for irrigation and fertilization

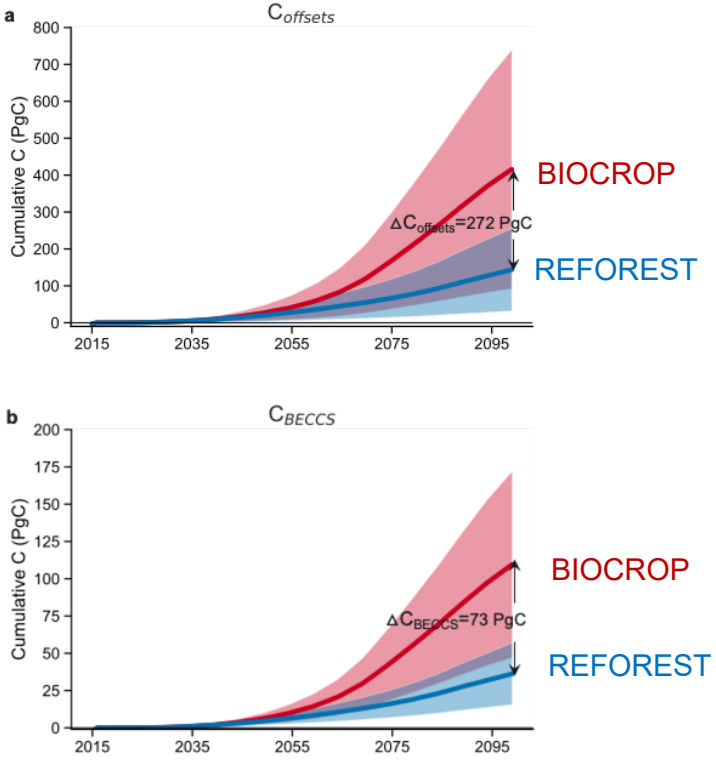
Cheng et al., 2019, JAMES



Bioenergy crops added to CESM

For BECCS, the fossil fuel substitution carbon offset and carbon capture and storage (CCS) efficiency are highly uncertain





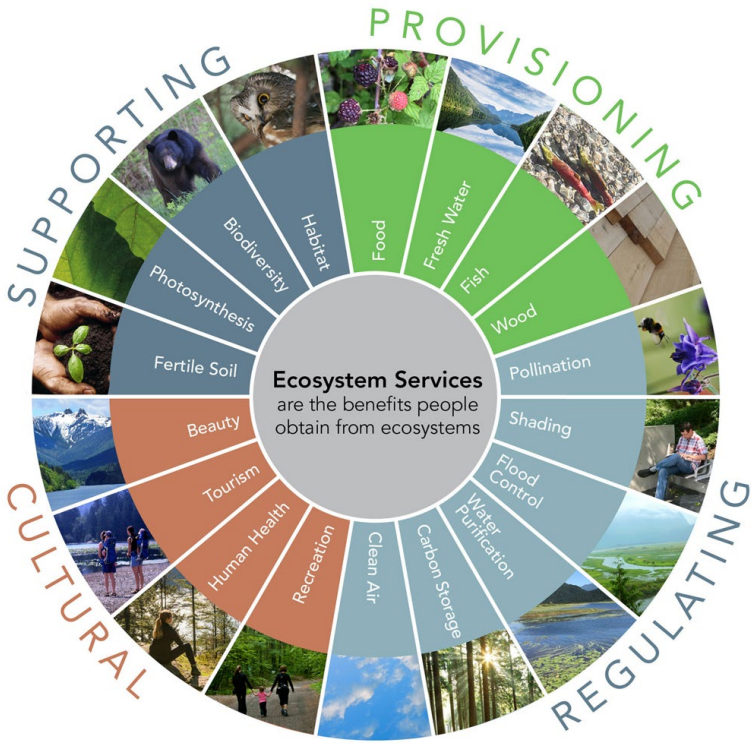
With rapid and large technological advances, BIOCROP could be a considerably larger effective carbon sink than REFOREST

With slow technological advances, BIOCROP could fail in its intended goals and even end up being a net carbon source

Other Constraints and Co-benefits for Land Based CDR

Land and nature is important for many other reasons

Potential for interventions to deliver on other core benefits for people & biodiversity



Source: Metro Vancouver Regional Planning 2018

Provides our food	Livelihoods of ~70% ppl
Habitat and biodiversity	Water quantity & quality
Bioenergy, minerals, fiber	Resilience, buffers extremes

Other Ecosystem and Societal Efforts with Land Based CDR

Countries and companies have agreed to address global challenges and deliver on multiple international agreements and goals

Climate

- UNFCCC Paris Agreement (Mitigation to limit warming to 1.5/2C, Adaptation)
- SDGs (climate action on mitigation and adaptation)
- Science-based Targets Initiative (SBTi)

People

- SDGs (poverty, livelihoods, food, health)
- Climate Justice who should be providing solutions to Emissions?
- Who should receive payment for carbon services? Who owns the land / carbon markets?

Nature

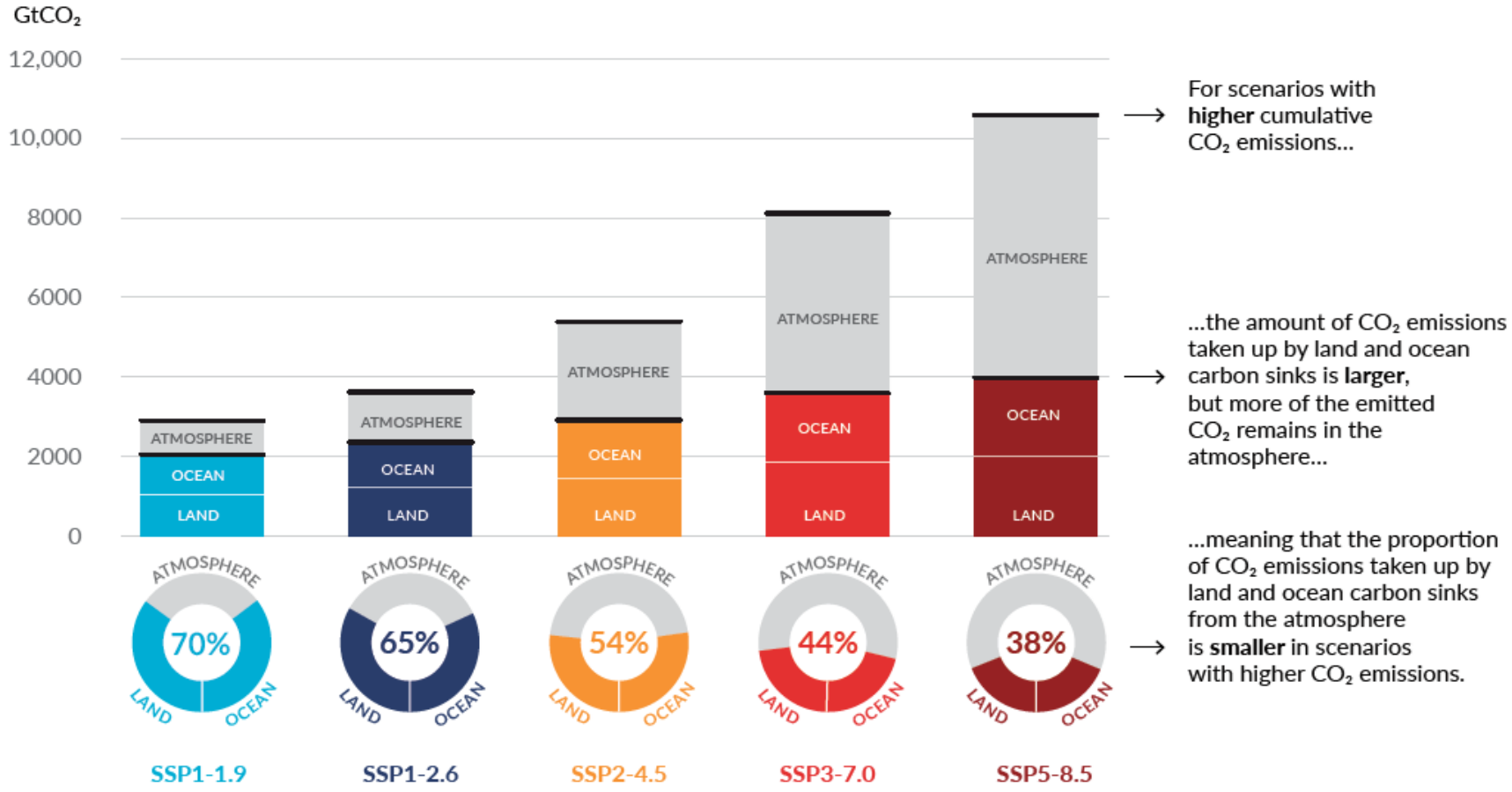
- UNCBD Biodiversity Framework (30% effective and inclusive conservation by 2030)
- UNCCD Land Degradation Neutrality (no net loss of healthy and productive land through Desertification)
- SDGs (biodiversity, ecosystems, water)
- Taskforce on Nature-related Financial Disclosures (TNFD)
- Science-based targets for Nature (SBTN)

Land needs to deliver on multiple needs beyond climate (including food, water, habitat). CDR interventions that focus on just one goal is a missed opportunity. Need to move towards maximizing multiple outcomes on climate, people and nature

Carbon Sink Growth Diminishes in Higher CO2 Pathways

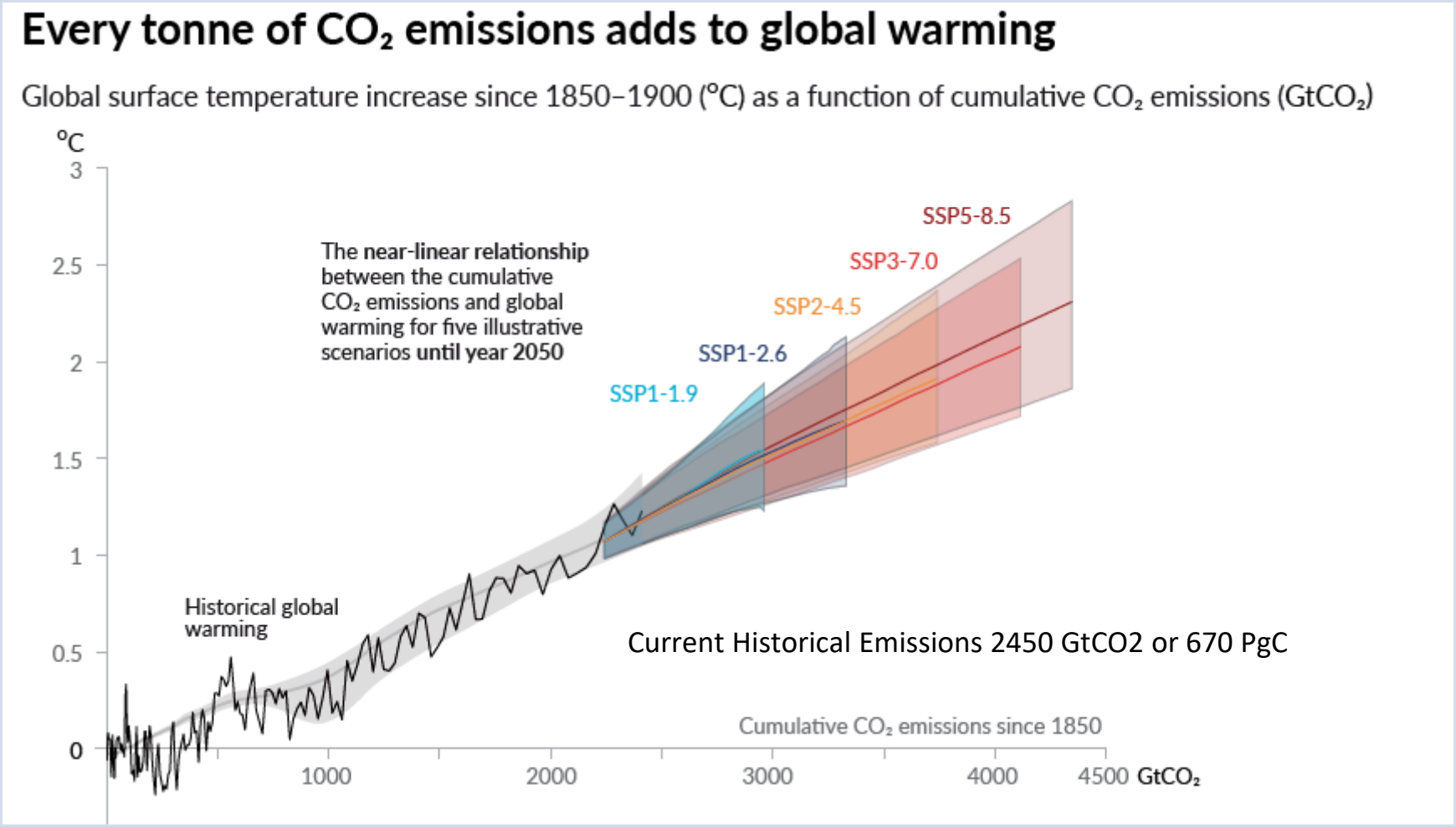
The proportion of CO_2 emissions taken up by land and ocean carbon sinks is smaller in scenarios with higher cumulative CO_2 emissions

Total cumulative CO_2 emissions **taken up by land and ocean** (colours) and remaining in the atmosphere (grey) under the five illustrative scenarios from 1850 to 2100



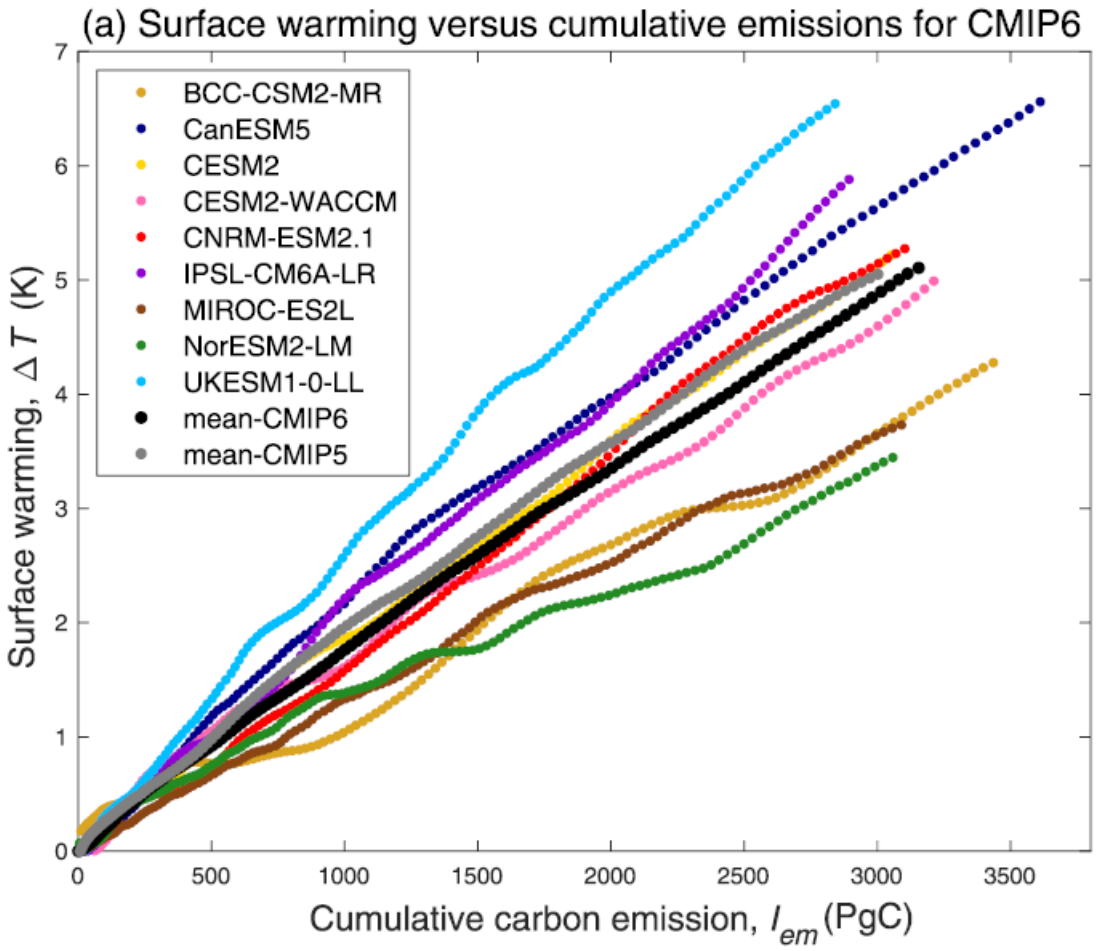
IPCC AR6

Uncertainty in TCRE and CDR



IPCC AR6

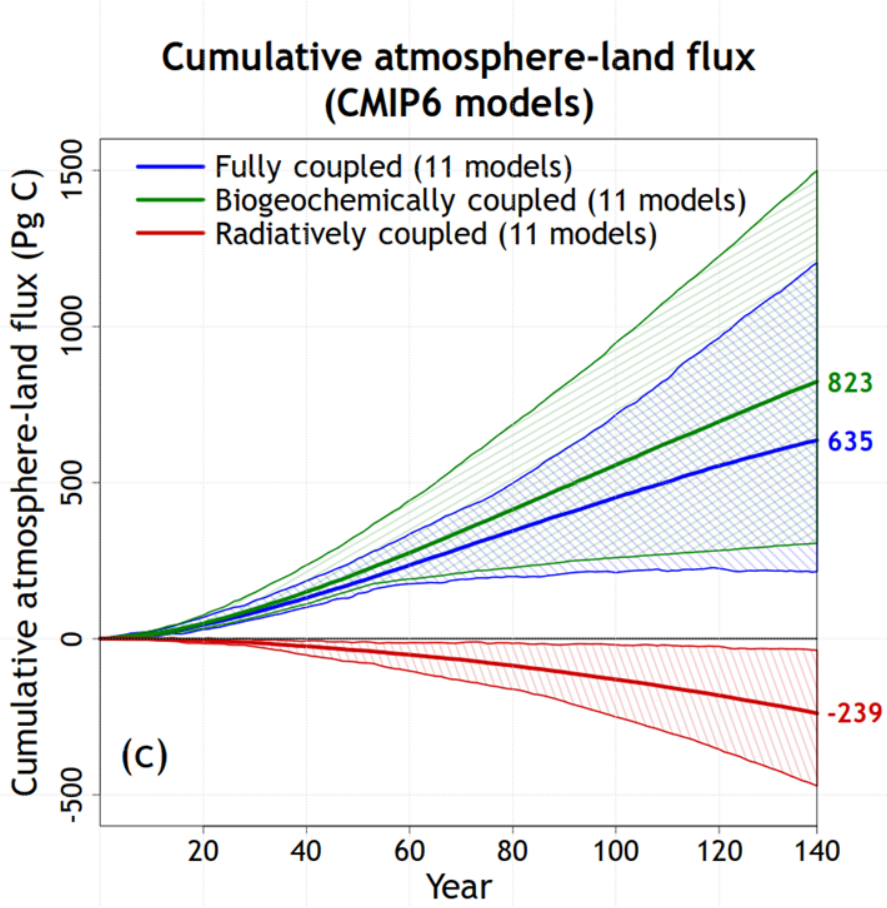
CMIP6 C4MIP Carbon Climate Uncertainties: 1% CO2 ramp

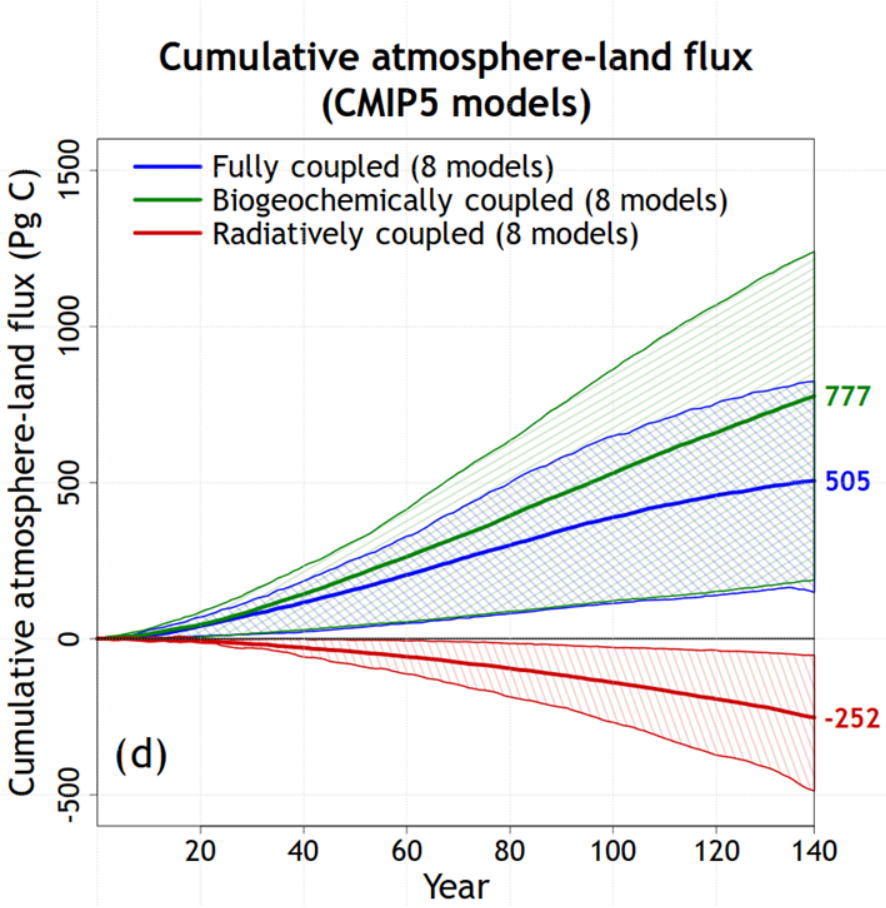


Williams et al 2020

Transient Climate Response to Emissions Uncertainty analysis based on simulations run with fully, radiatively, and biogeochemically coupled model configurations of an Earth system model with Atmospheric CO_2 ramped at 1% increase annually from pre Industrial to 4xCO2.

CMIP6 C4MIP Carbon Climate Uncertainties: 1% CO2 ramp

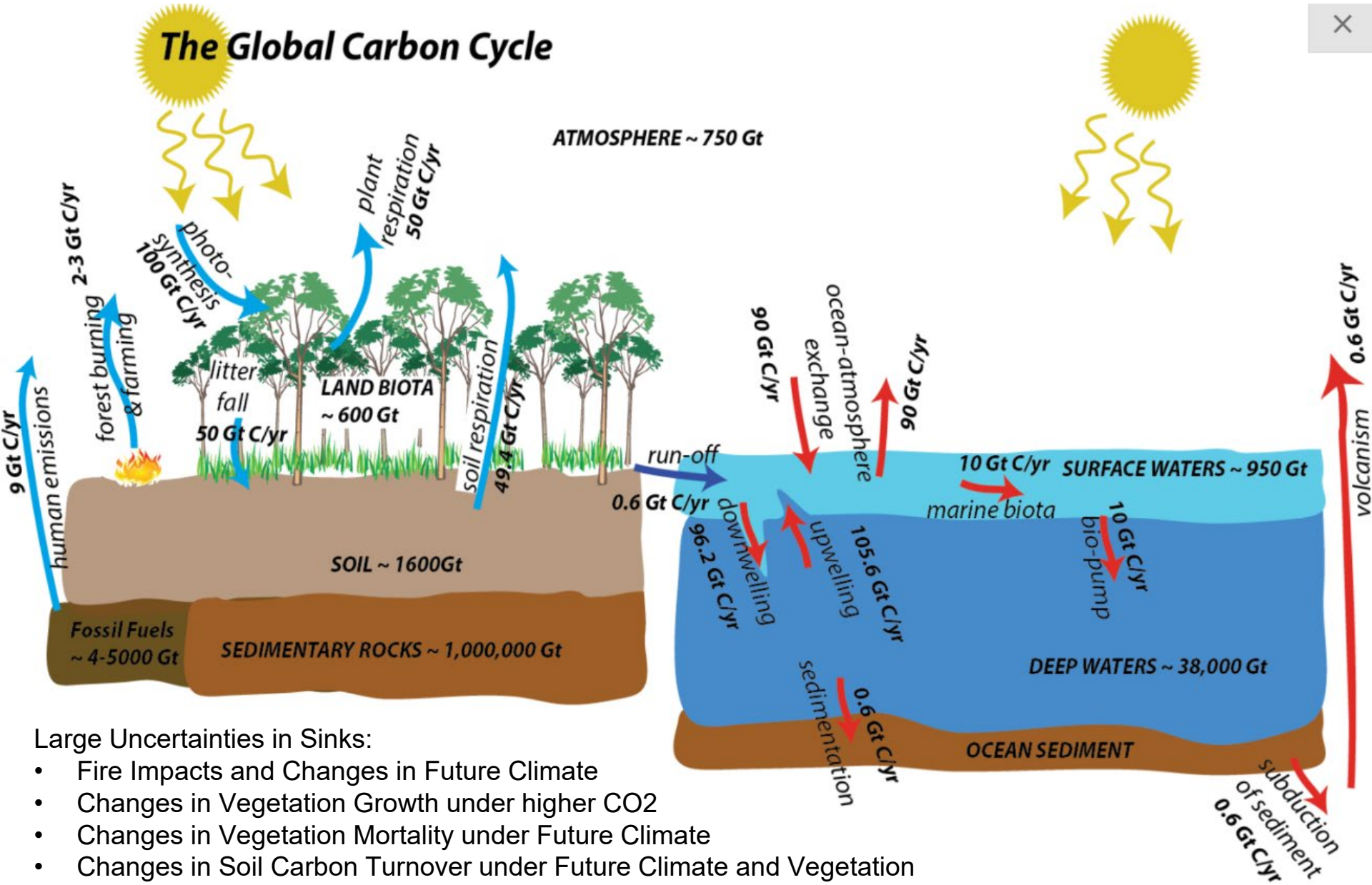




Arora et al. (2020) Biogeosciences

Carbon feedbacks analysis based on simulations run with fully, radiatively, and biogeochemically coupled model configurations of an Earth system model with Atmospheric CO_2 ramped at 1% increase annually from pre Industrial to 4xCO2.

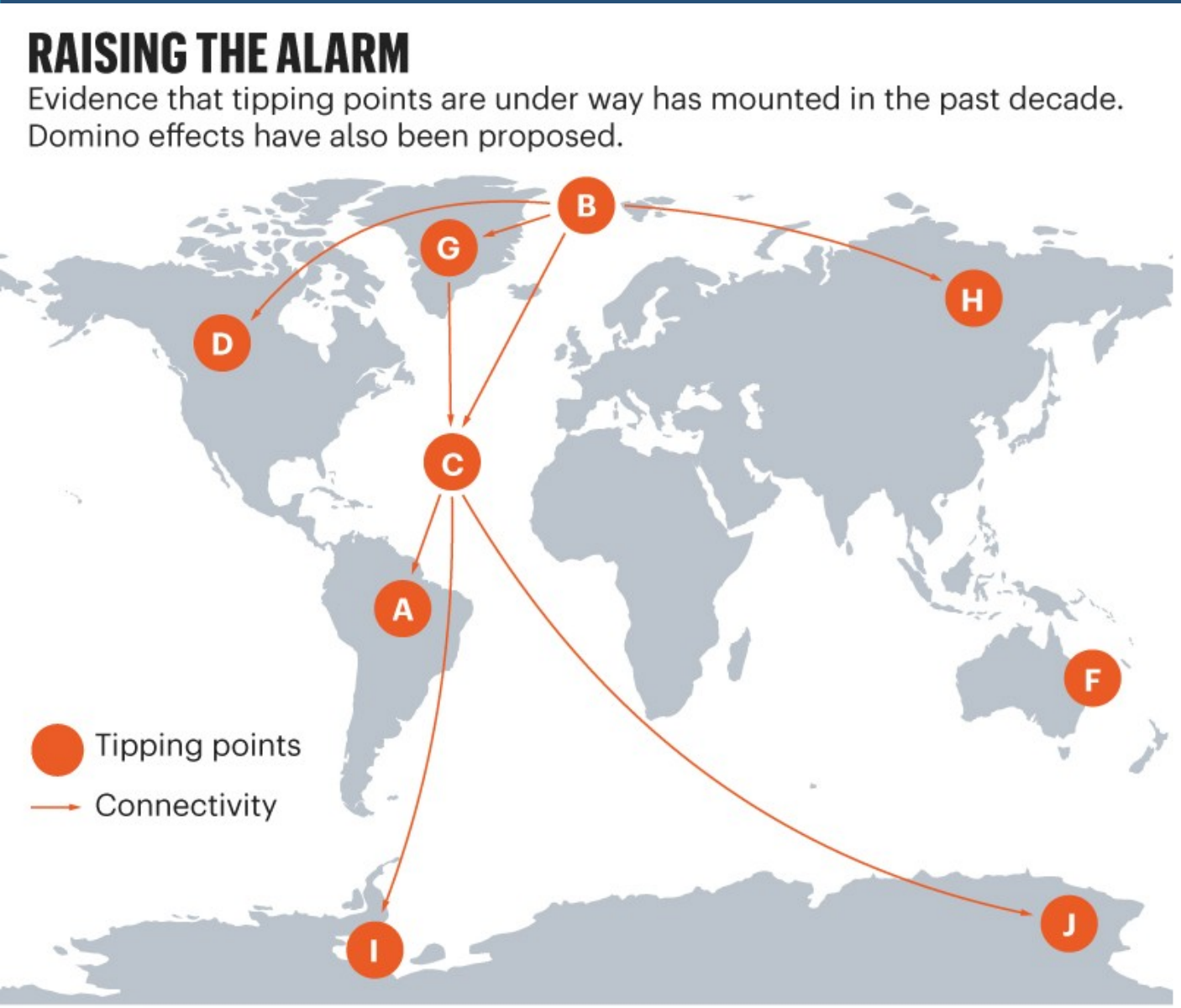
Global Carbon Cycle Reservoirs and Fluxes



Large Uncertainties in Sinks:

- Fire Impacts and Changes in Future Climate
- Changes in Vegetation Growth under higher CO2
- Changes in Vegetation Mortality under Future Climate
- Changes in Soil Carbon Turnover under Future Climate and Vegetation

Climate Tipping Points and Carbon Vulnerability



A. Amazon rainforest
Frequent droughts

B. Arctic sea ice
Reduction in area

C. Atlantic circulation
In slowdown since 1950s

D. Boreal forest
Fires and pests changing

F. Coral reefs
Large-scale die-offs

G. Greenland ice sheet
Ice loss accelerating

H. Permafrost
Thawing

I. West Antarctic ice sheet
Ice loss accelerating

J. Wilkes Basin,
East Antarctica
Ice loss accelerating

Lentin et al. (2019) Nature

Thank You – Questions?