Governing the (temporary) climate overshoot and carbon dioxide removal

Masahiro Sugiyama

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IPCC AR7 CLA
(Working Group 3, Chapter 15) (2025-)

GESAMP WG 41
(formerly marine geoengineering) member

AI use: this English version was translated from the author’s Japanese slides and laid out with Claude (Anthropic); the added figures and quotations were selected with it. Sources and wording checked by the author.

Self-introduction: Masahiro Sugiyama

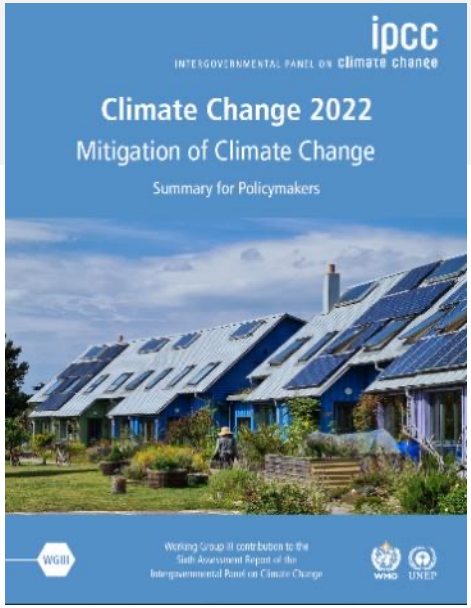
Research area: long-term climate policy

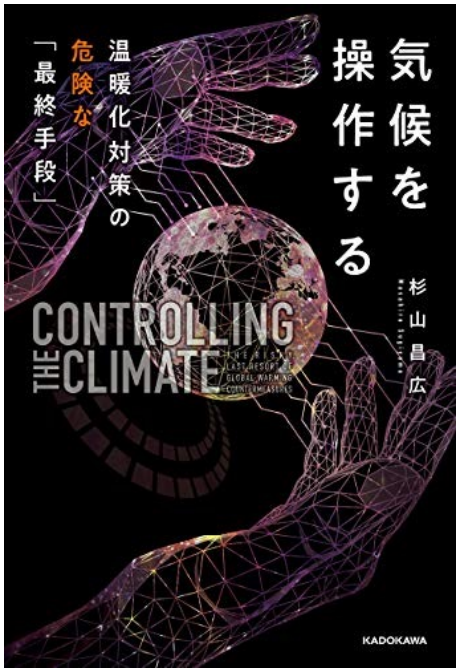
Recent research topics

- Climate policy
  - ✓ Scenario analysis
  - ✓ Policy analysis
  - ✓ EBPM/EIPM
- Climate engineering
  - ✓ Governance
  - ✓ Public engagement

Methods

- Mainly applied environmental economics



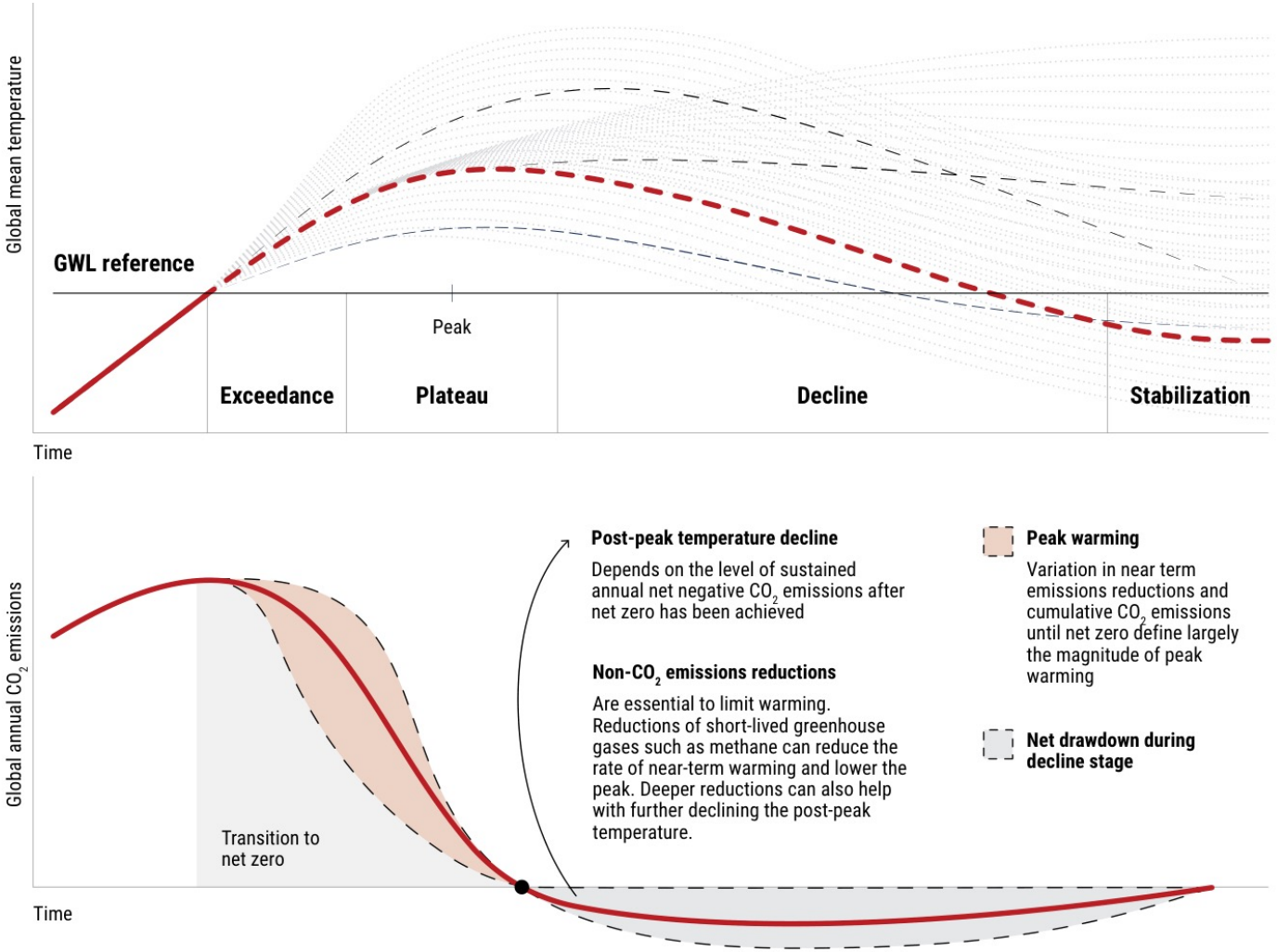


UNEP, “Limiting Overshoot” (2 September 2026)

“Under current policies and alternative near-term trajectories, exceedance of 1.5° C is now widely assessed as unavoidable.”

— United Nations Environment Programme (UNEP), Limiting Overshoot (2026), p. 15

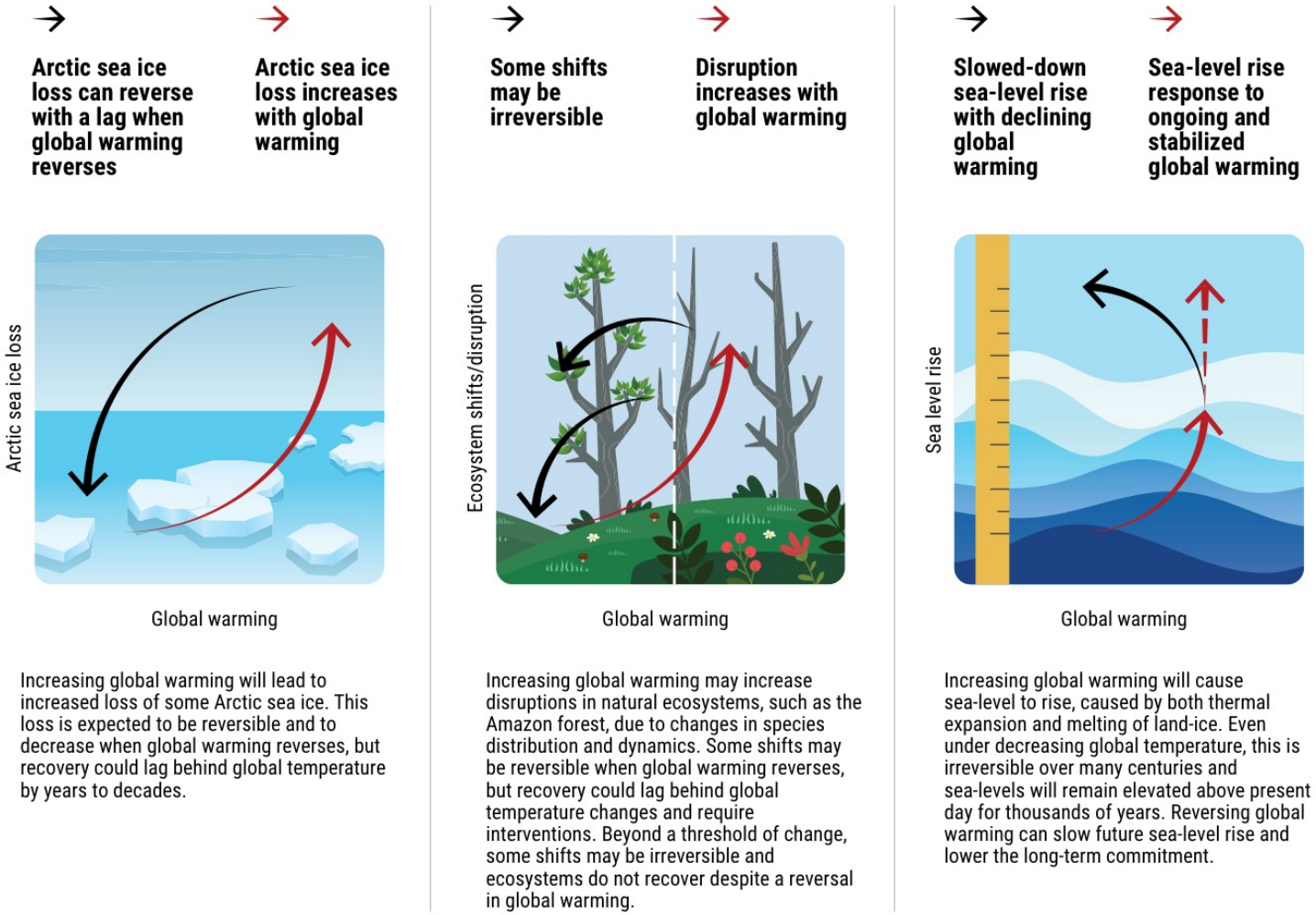
“Key pathway concepts”



“Pursuing efforts to limit warming to 1.5°C—while minimizing the magnitude and duration of overshoot—requires immediate and deep emissions reductions across all sectors.”

— United Nations Environment Programme (UNEP), Limiting Overshoot (2026), p. 15

“Reversible, partially reversible and irreversible dynamics of Earth system components under global warming decline”



“Slow-responding components of the Earth system—such as permafrost thaw, glacier land ice sheet loss, and sea level rise—are particularly prone to impact irreversibility.”

— United Nations Environment Programme (UNEP), Limiting Overshoot (2026), p. 23

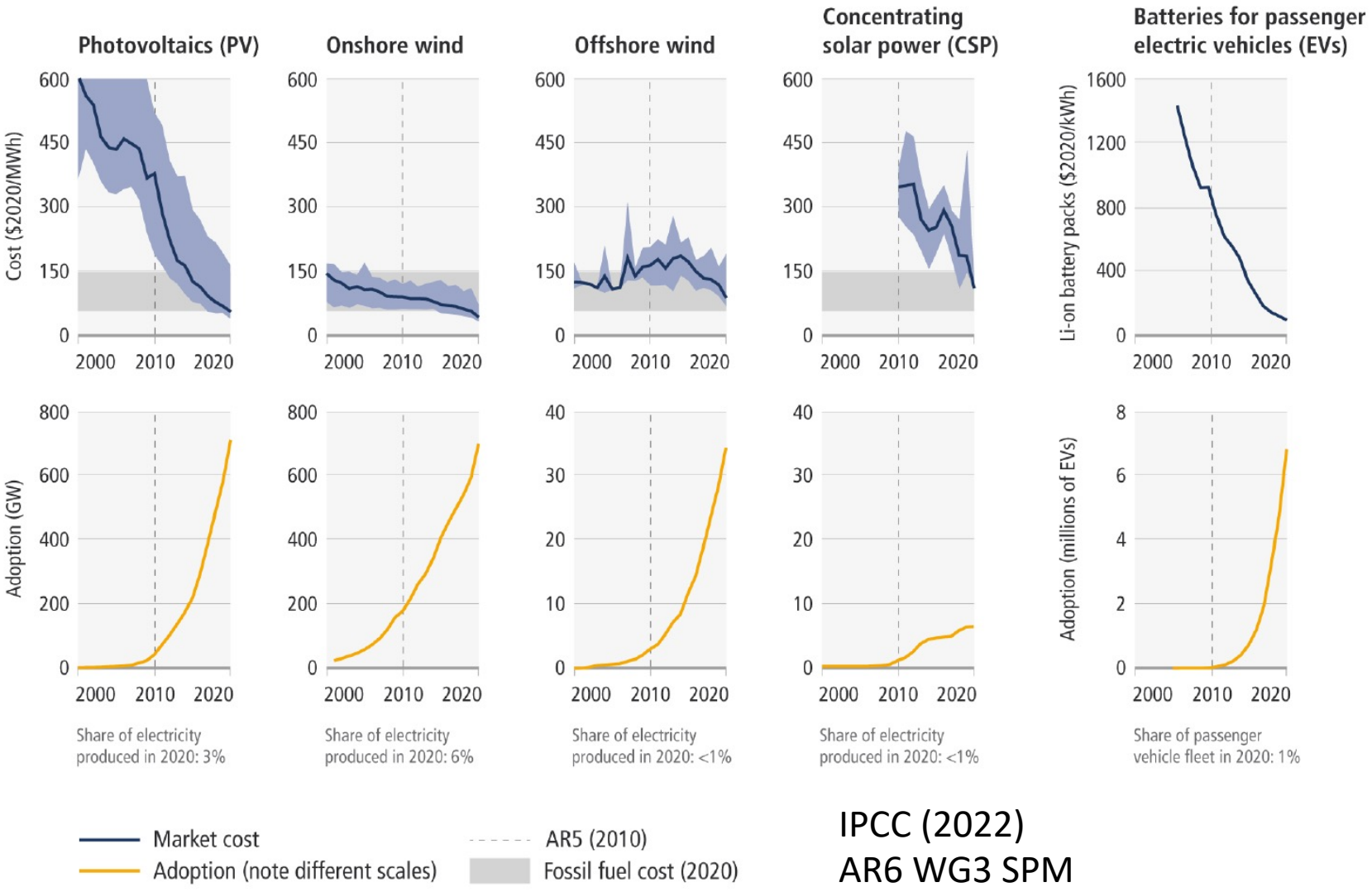
Climate action is advancing, but overshoot is looming

More precisely, temporary overshoot

The importance of carbon dioxide removal (CDR) / carbon removal

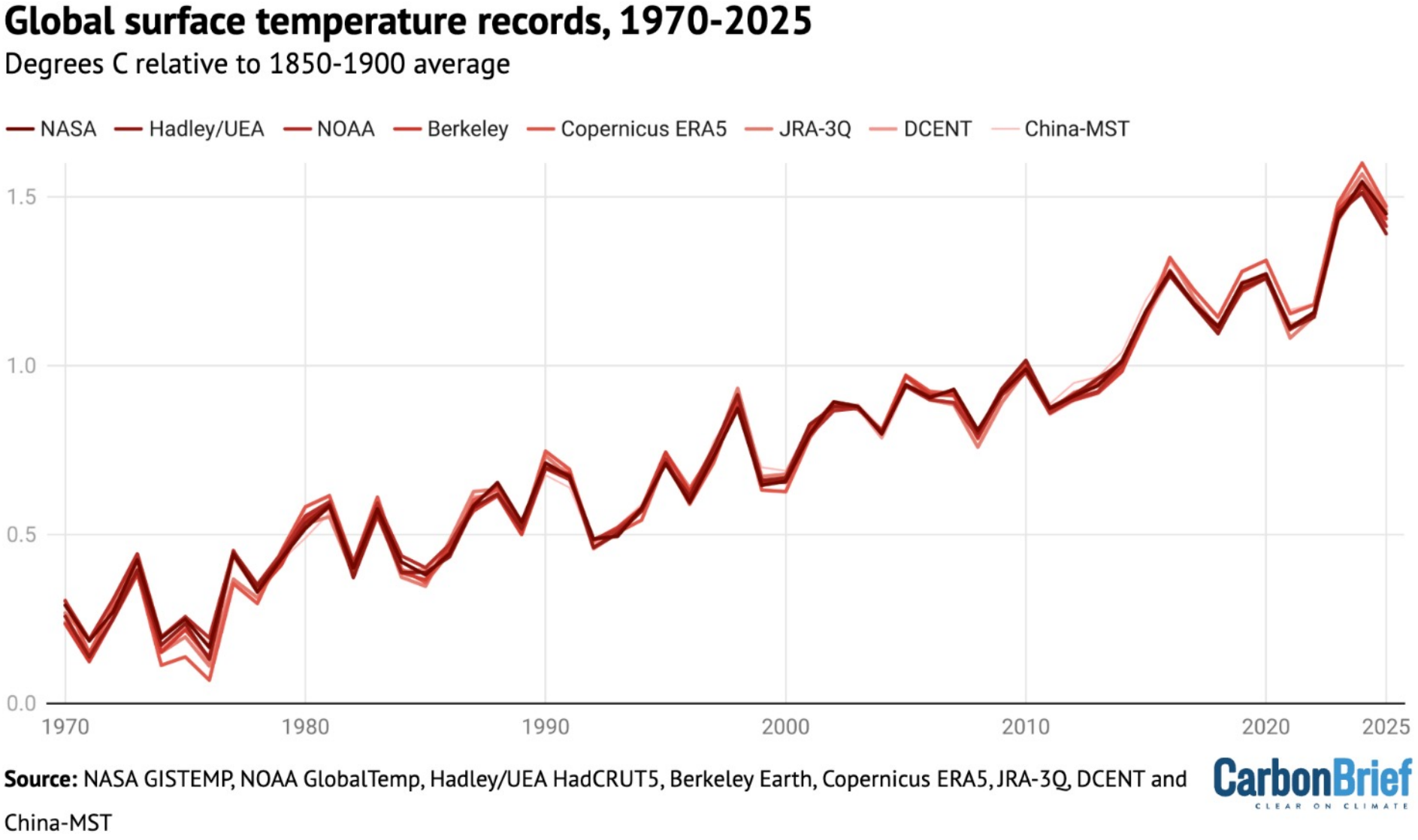
Mitigation is advancing steadily, and technology is improving remarkably fast (Japan excepted)

The unit costs of some forms of renewable energy and of batteries for passenger EVs have fallen, and their use continues to rise.



IPCC (2022)
AR6 WG3 SPM

Climate change / global warming continues



https://www.carbonbrief.org/state-of-the-climate-2025-in-top-three-hottest-years-on-record-as-ocean-heat-surges/

Worsening climate impacts (causal inference is hard, but attribution has advanced)

news.yahoo.co.jp/articles/67bb64f62ae43c3eb32b9855724931abe66a5213

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TBS NEWS DIG

TBS NEWS DIG Powered by JNN

youtube.com/watch?v=x1rAzUGyG0A

Premium JP　検索

岩手・大槌町の山火事の焼失面積「羽田空港」超え　土の中に“くすぶる火”　ついに雨降るも1時間降水量は2.5ミリ程度（2026年04月27日）

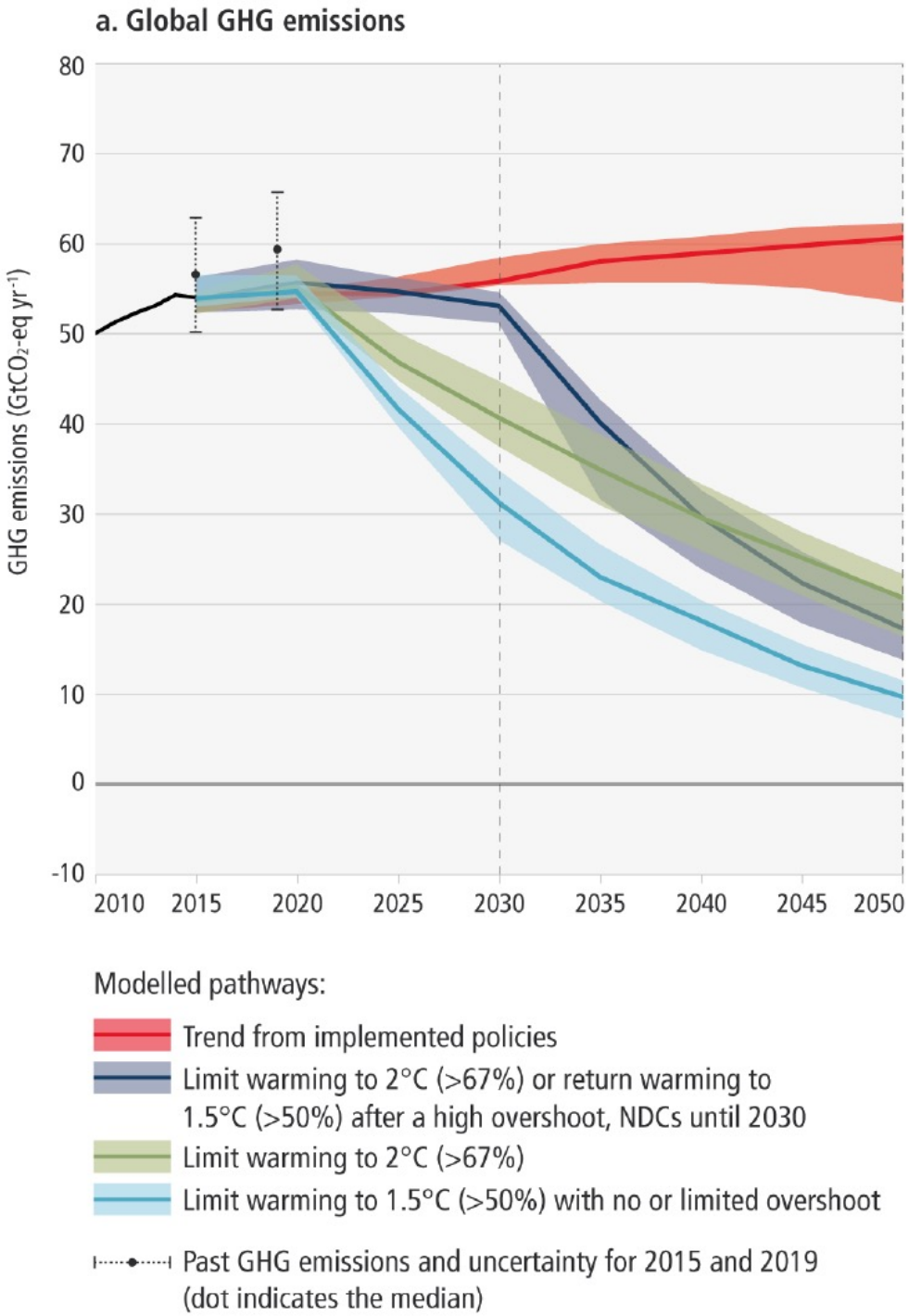
FNNプライムオンライン　チャンネル登録者数 234万人　チャンネル登録　233　共有　質問する　保存

International climate governance and goals

- Goals
  - ✓ 1992 UN Framework Convention on Climate Change (UNFCCC)
    - ✓ Stabilization at a level that would prevent dangerous anthropogenic interference with the climate system
  - ✓ 1997 Kyoto Protocol (under the UNFCCC)
    - ✓ Emission reduction obligations for developed countries; no target for the climate itself
  - ✓ 2015 Paris Agreement
    - ✓ Holding the increase in global average temperature to well below 2° C above pre-industrial levels, and pursuing efforts to limit it to 1.5° C
  - ✓ 2021 Glasgow Climate Pact
    - ✓ The two-tier formulation “well below 2° C / efforts towards 1.5° C” → emphasis on 1.5° C

International progres

Mitigation is accelerating, but the world still contains developing countries that will grow economically, and against the Paris Agreement's 2° C and 1.5° C goals the pace of emission reductions is far too slow

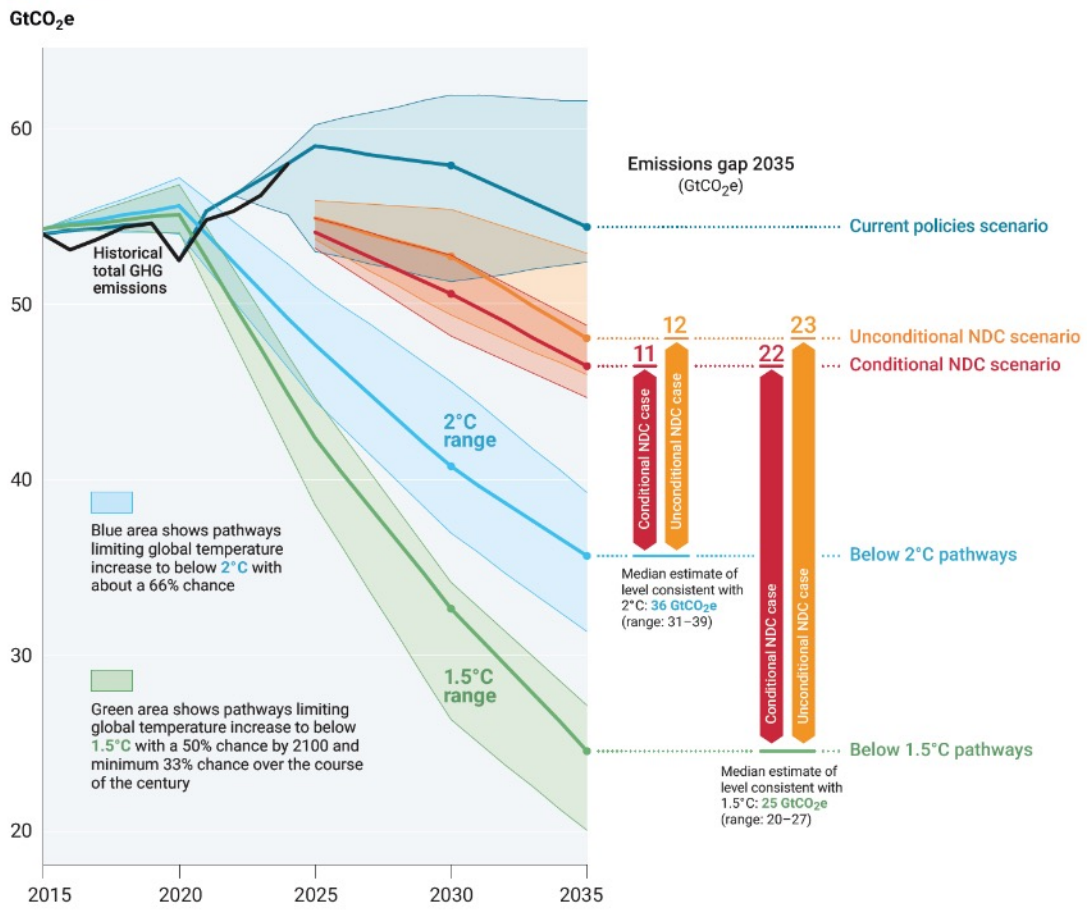


IPCC (2022) AR6 WG3 SPM

International progress

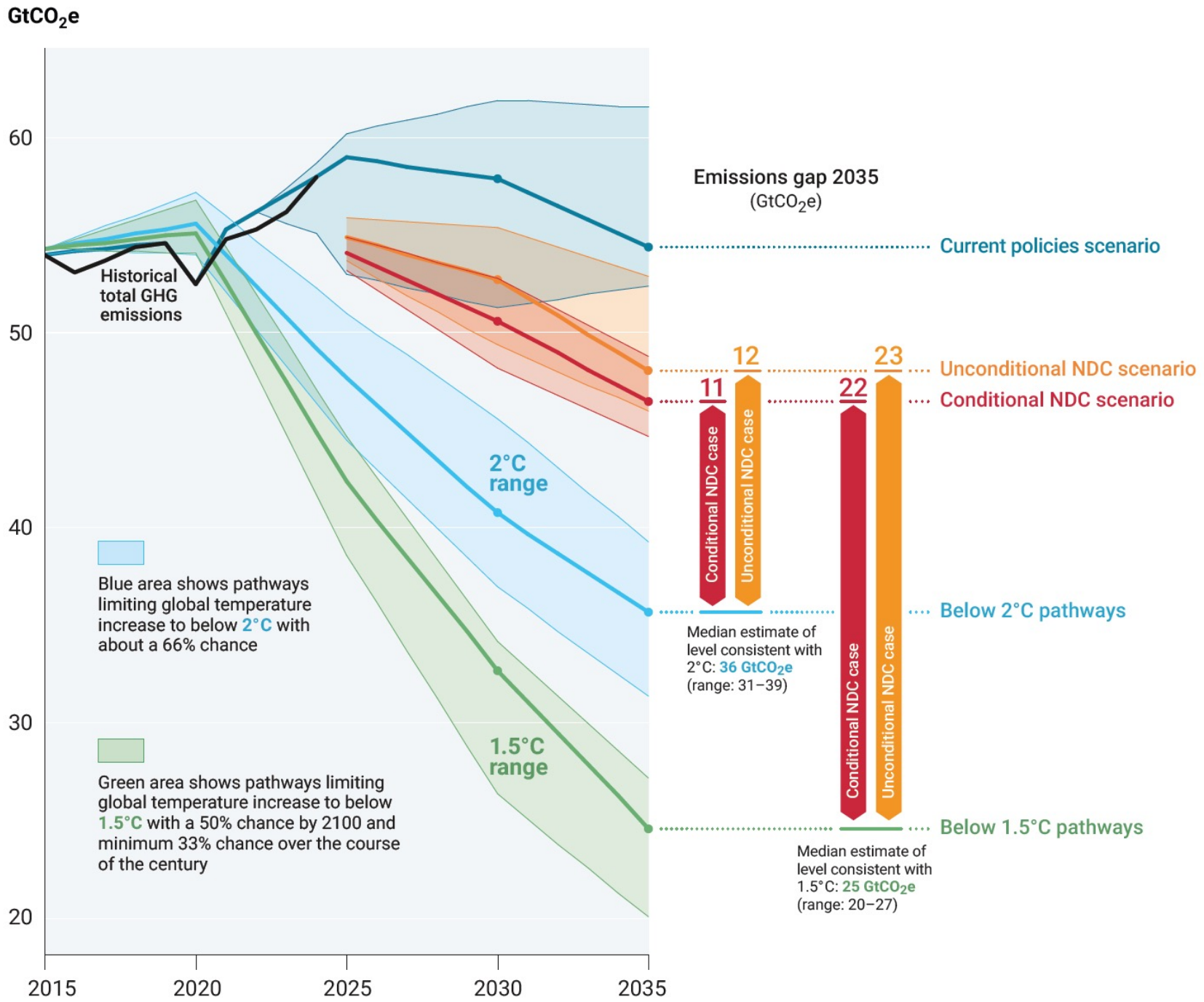
Mitigation is accelerating, but the world still contains developing countries that will grow economically, and against the Paris Agreement's 2° C and 1.5° C goals the pace of emission reductions is far too slow

Figure ES.5 Global GHG emissions under different scenarios and the emissions gap in 2030 and 2035

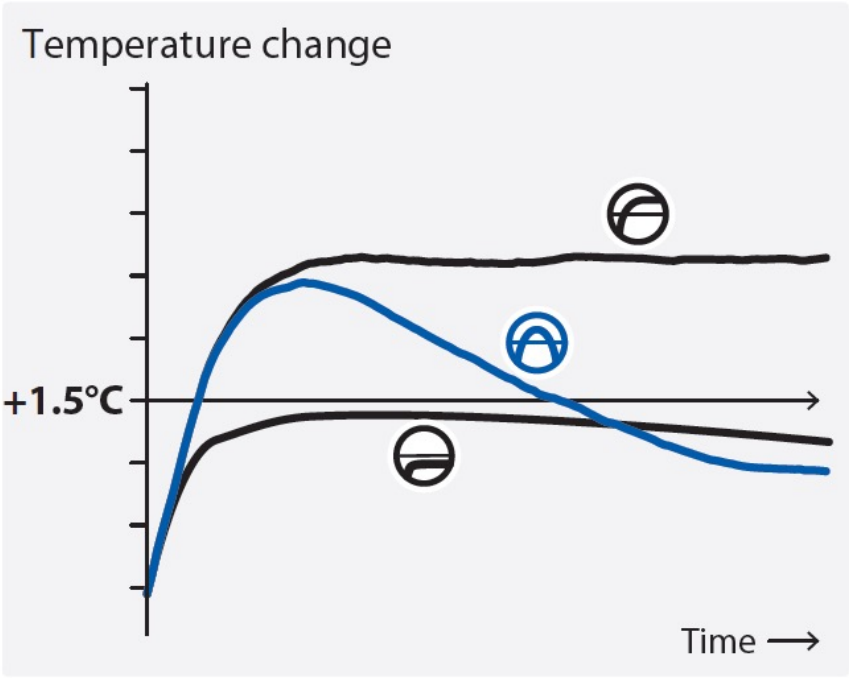


UNEP (2025)

Figure ES.5 Global GHG emissions under different scenarios and the emissions gap in 2030 and 2035



Exceeding 1.5° C?



Exceed and stabilize
Global warming rises beyond a specific level and remains consistently above that level over the long term

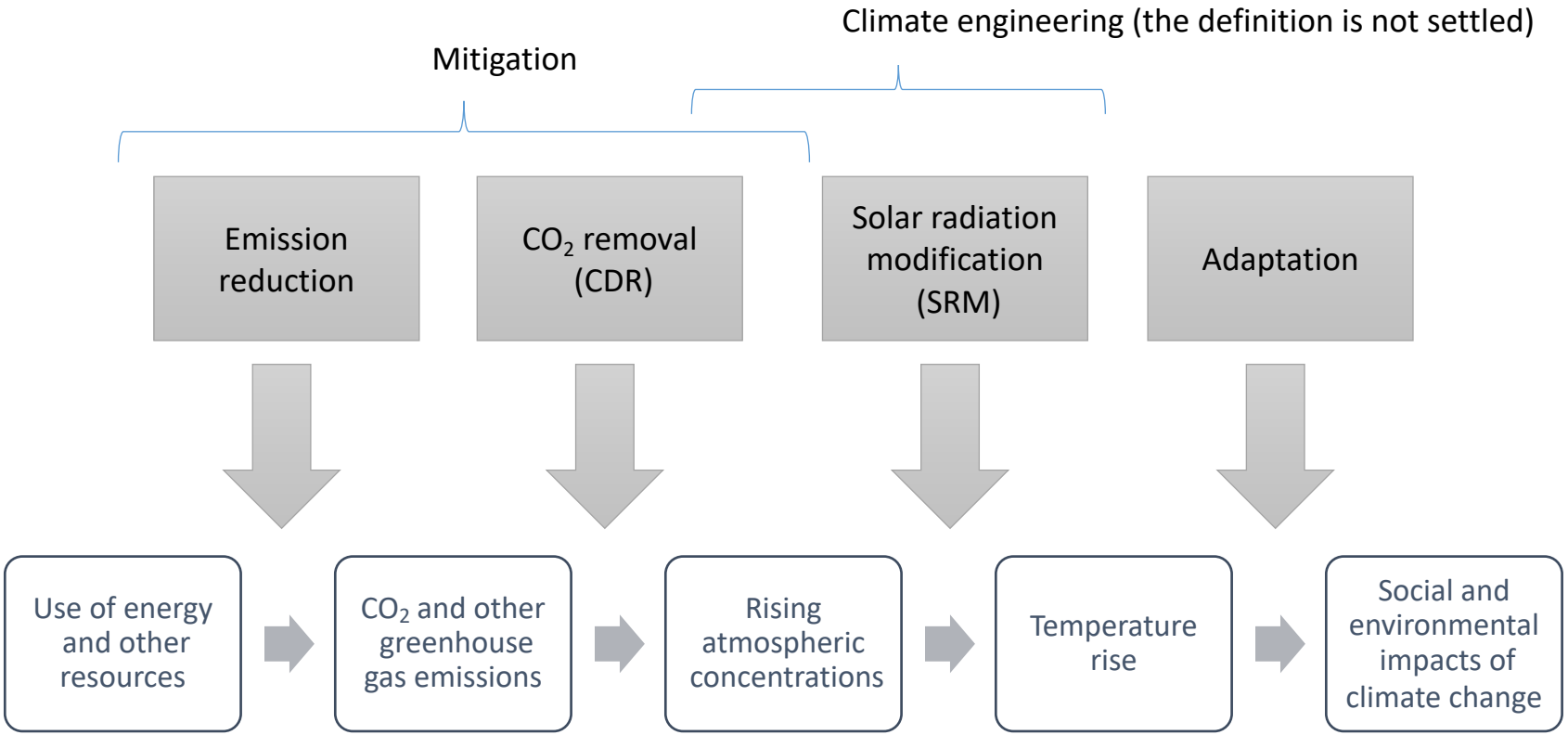
Overshoot: exceed and decline
Global warming first exceeds a specified level and then returns to or declines below that level before a specified period of time

Remain below 1.5°C
A world where global warming would never have exceeded 1.5°C above preindustrial levels

Reisinger et al. (2025)
https://doi.org/10.1146/annurev-environ-111523-102029

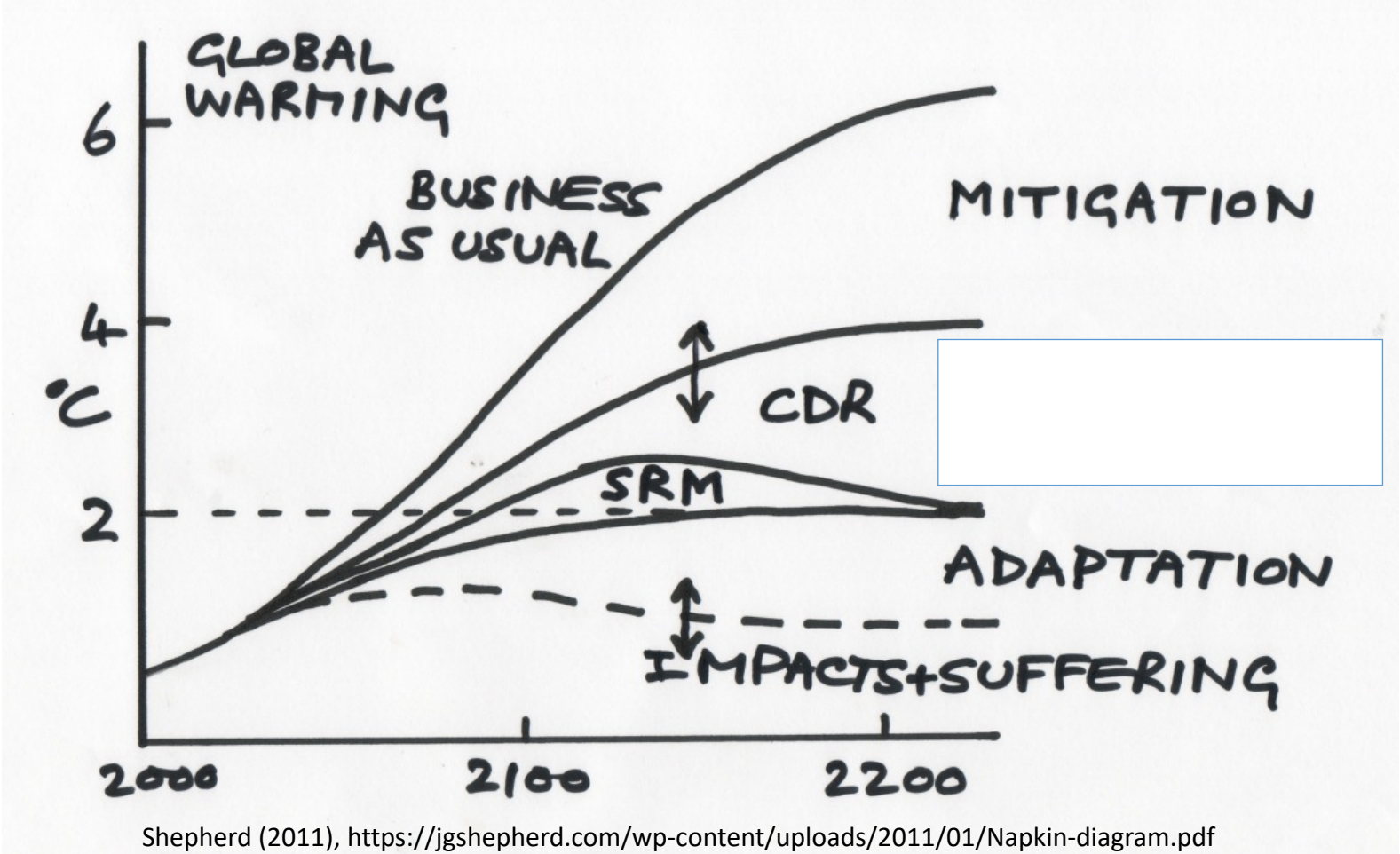
Portfolio of climate responses

Portfolio of climate responses



Combining multiple options (napkin diagram)

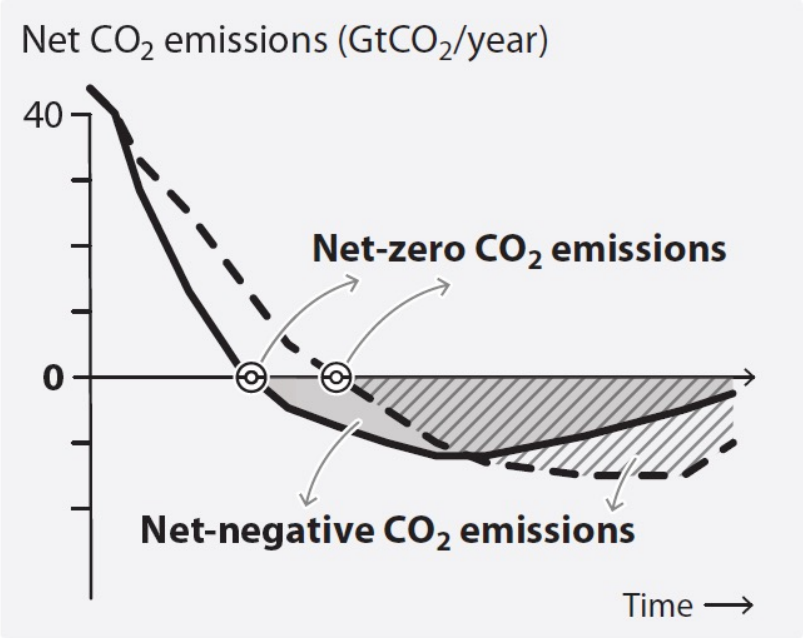
- SRM (solar radiation modification): sunlight reflection to cool the climate
- CDR (carbon dioxide removal): reduce atmospheric CO_2 concentration
- (I am intentionally masking “geoengineering”)



Shepherd (2011), https://jgshepherd.com/wp-content/uploads/2011/01/Napkin-diagram.pdf

Getting back from a (climate) overshoot requires carbon dioxide removal / carbon removal

Exceeding 1.5° C?



Net-zero CO_2 emissions
When the amount of CO_2 released into the atmosphere is balanced by the amount removed, global emissions reach net zero and global temperature reaches its peak

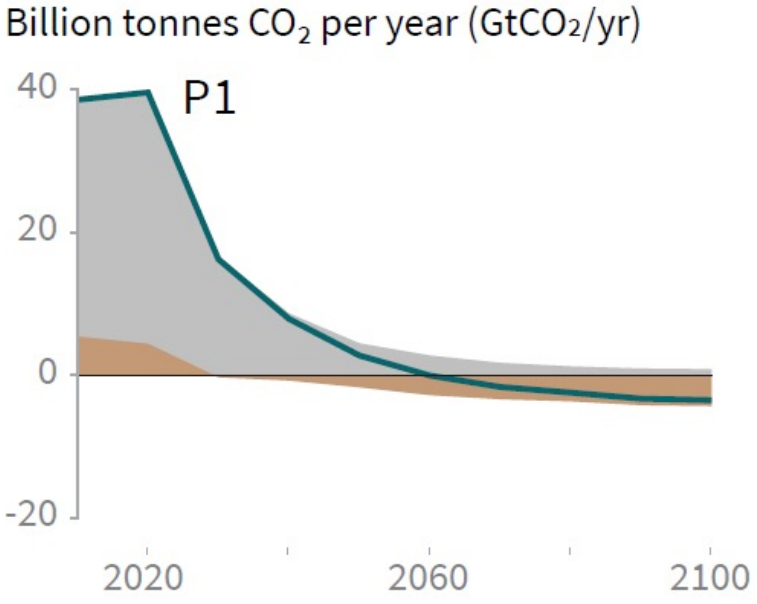
Net negative CO_2 emissions
When more CO_2 is removed from the atmosphere than is being emitted, global temperatures start declining again

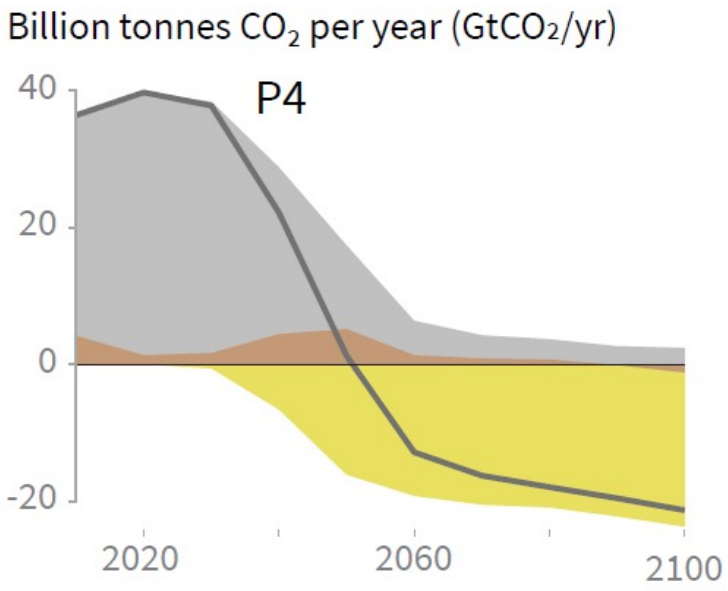
Non-CO_2 emissions
CO_2 is the dominant driver of warming, but non-CO_2 forcers also contribute to the temperature peak and decline

Reisinger et al. (2025)
https://doi.org/10.1146/annurev-environ-111523-102029

IPCC (2018) 1.5 °C Special Report

Fossil fuel and industry AFOLU BECCS

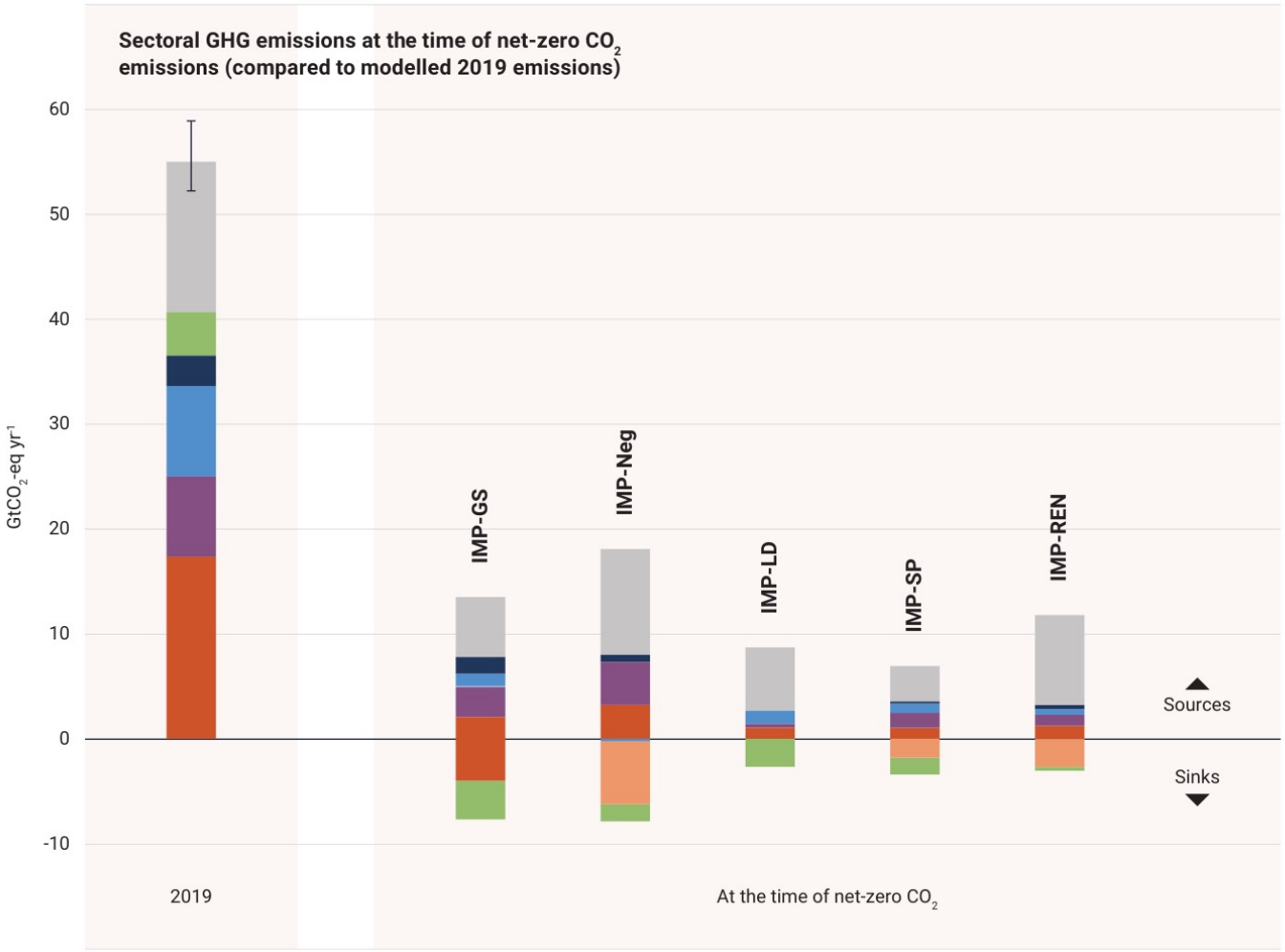




P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

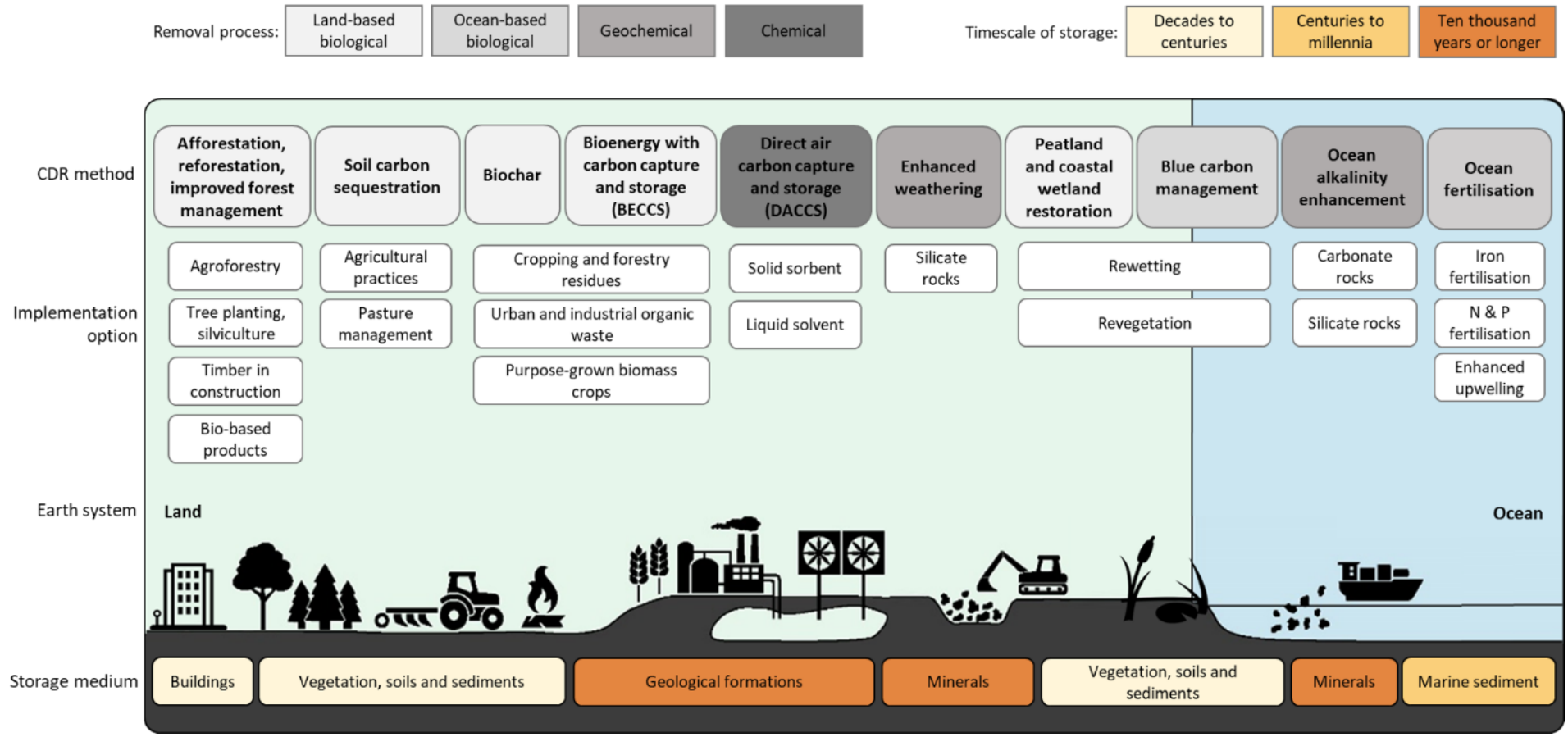
P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

“Examples of residual GHG emissions and CO_2 removals at the time of global net-zero CO_2 emissions …”

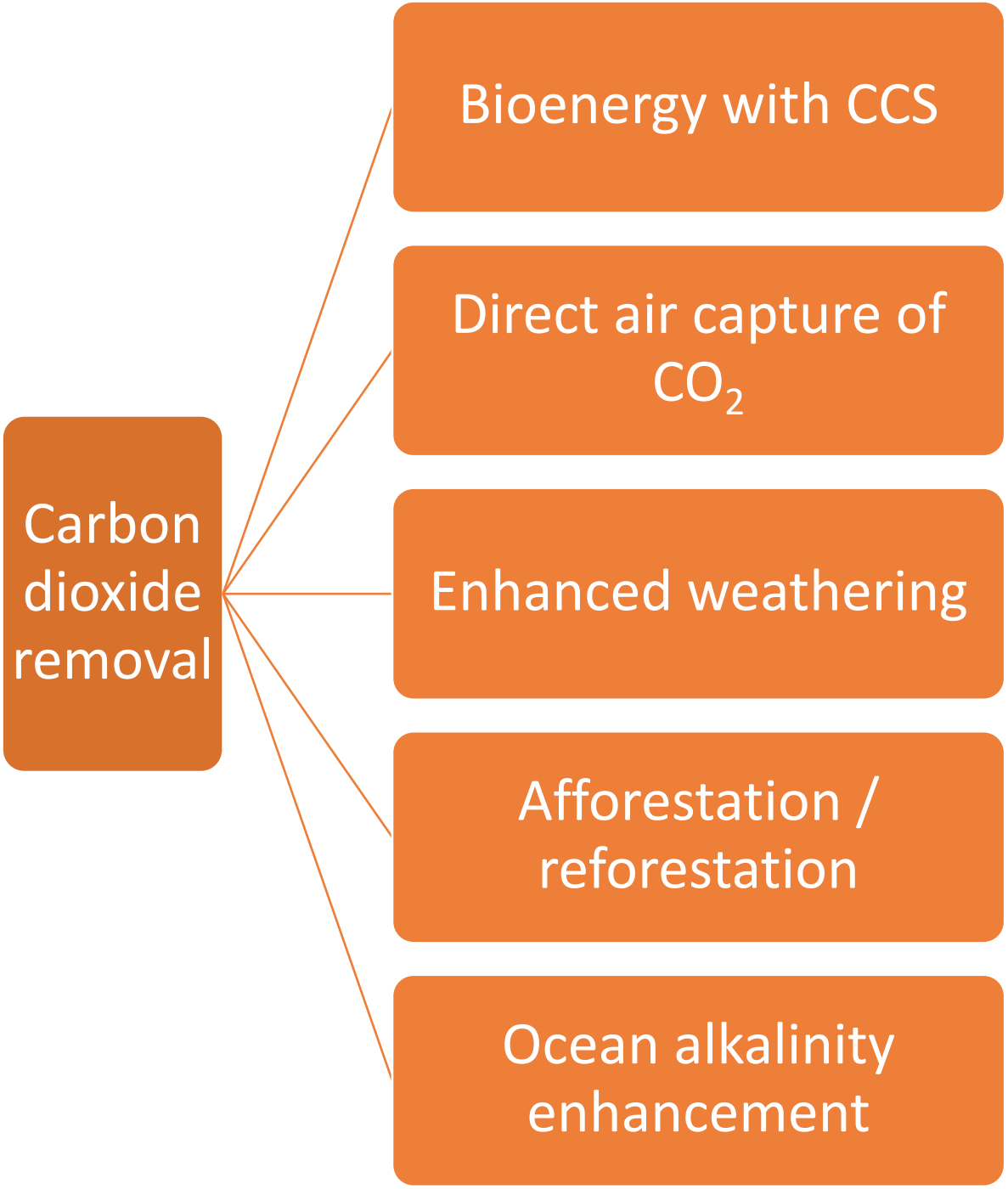


“… it would take about 100 years of sustained afforestation and forest management activities at the current scale to reduce global temperature by 0.1°C.”

— United Nations Environment Programme (UNEP), Limiting Overshoot (2026), p. 54



IPCC AR6 WG3 Chapter 12



Bioenergy is carbon neutral and combining it with CCS makes it CDR

Similar technologies already used in a submarine or the International Space Station

Accelerates chemical weathering that in nature absorbs CO_2 on a millennial timescale

Benign on a small scale; large-scale afforestation/reforestation is a different matter

Enhances alkalinity by adding crushed rocks to the oceans

Summary of CDR options

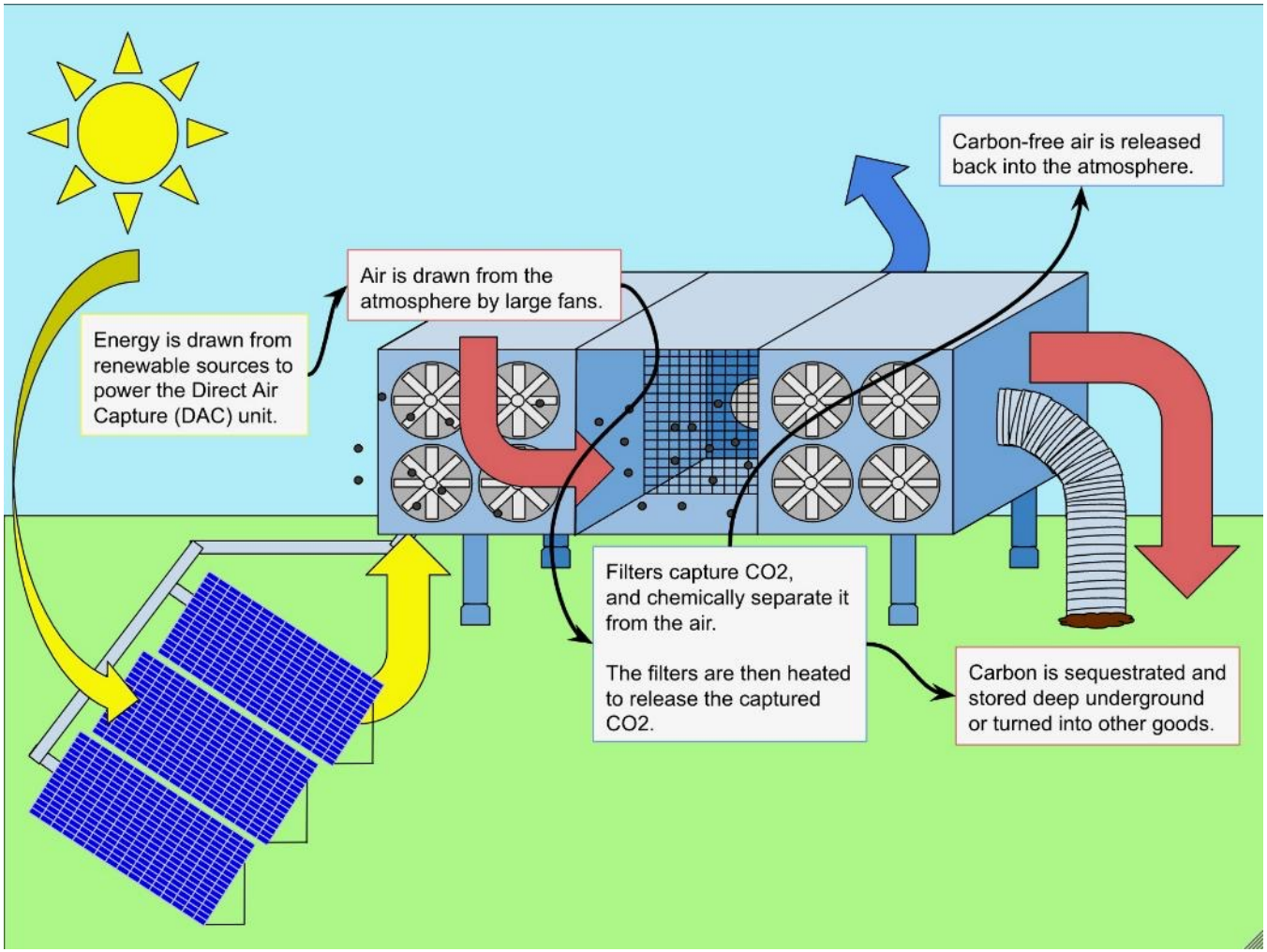
(There are many options but because of low technological readiness level (TRL), they aren't represented in scenarios)

CDR option	TRL	Cost (USD/tCO2)	Potential (GtCO2/yr)	Risks and impacts
DACCS (direct air carbon dioxide capture & storage)	6	100-300 (84-386)	5-40	Increase demand of energy & water
BECCS (bioenergy with carbon capture and storage)	5-6	15-400	0.5-11	Competition among biomass and food over land and water Ecosystem impacts
(large-scale) afforestation and reforestation	8-9	0-240	0.5-10	Wildfires could release carbon back
Enhanced weathering	3-4	50-200 (24-578)	2-4 (<-1-95)	Impacts and pollution from mining

(Adapted from IPCC AR6 WG3 Ch12 Table 12.6)

Direct air capture (DACCS)

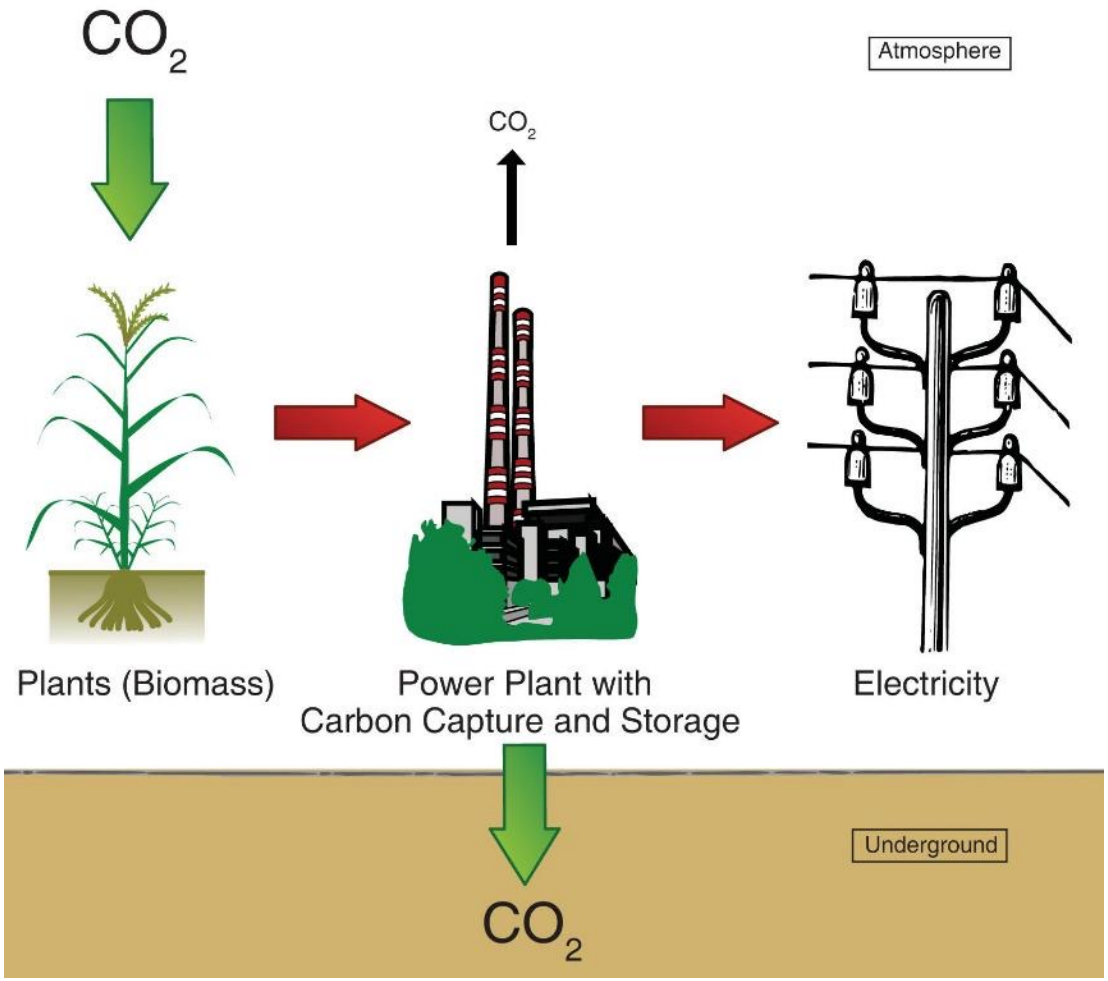
CO_2 is captured from ambient air with chemical sorbents, then stored underground



How a direct air capture plant works, schematically

Bioenergy with CCS (BECCS)

Biomass takes CO_2 from the air; capturing it at the power plant makes the cycle net-negative



A bioenergy power plant with carbon capture and storage

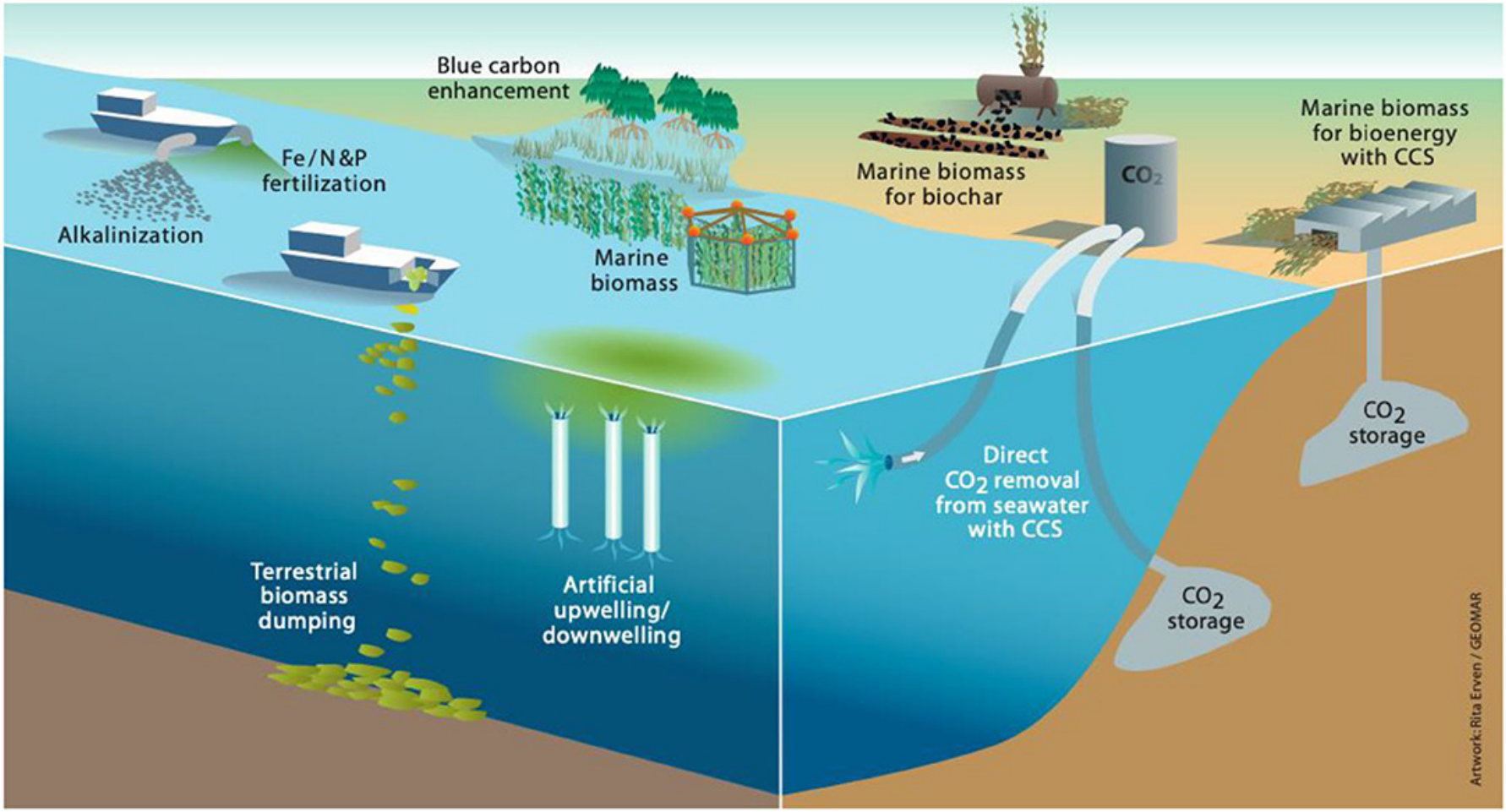
Biochar

Pyrolysis turns biomass into a char that resists decay for decades to centuries in soil

Woody biomass pyrolysed in a Kon-Tiki kiln — the pyrolysis step that makes biochar

Marine carbon dioxide removal (mCDR)

A family of options that use the ocean's own carbon cycle — the subject of GESAMP WG 41

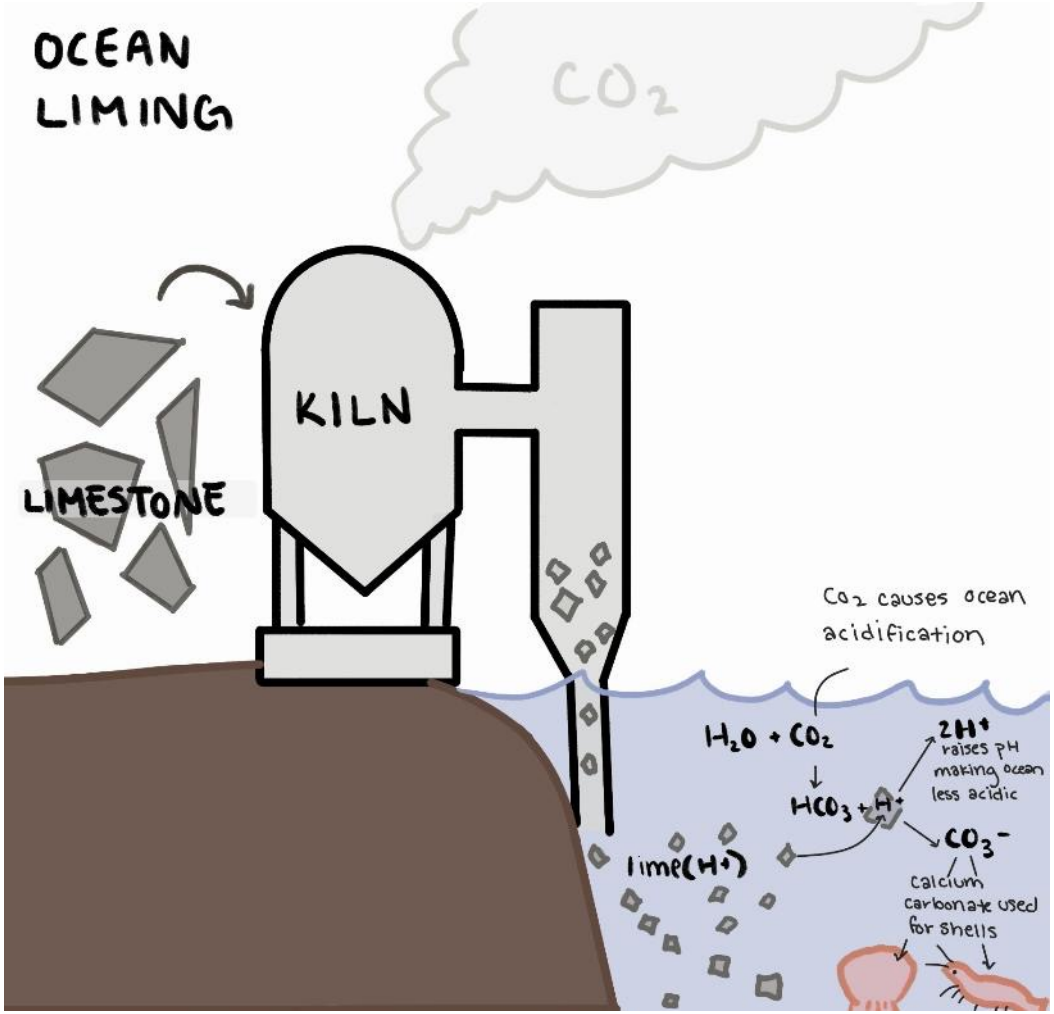


Proposed marine CDR options

"Proposed marine carbon dioxide removal options". Miranda Boettcher et al.. CC BY-SA 4.0. Source: doi: 10.3389/fclim.2021.664456. Wikimedia Commons, reused under the licence stated.
https://commons.wikimedia.org/wiki/File:Proposed_marine_carbon_dioxide_removal_options.jpg

Ocean alkalinity enhancement (OAE)

Adding alkalinity to seawater shifts the carbonate system and draws down atmospheric CO_2

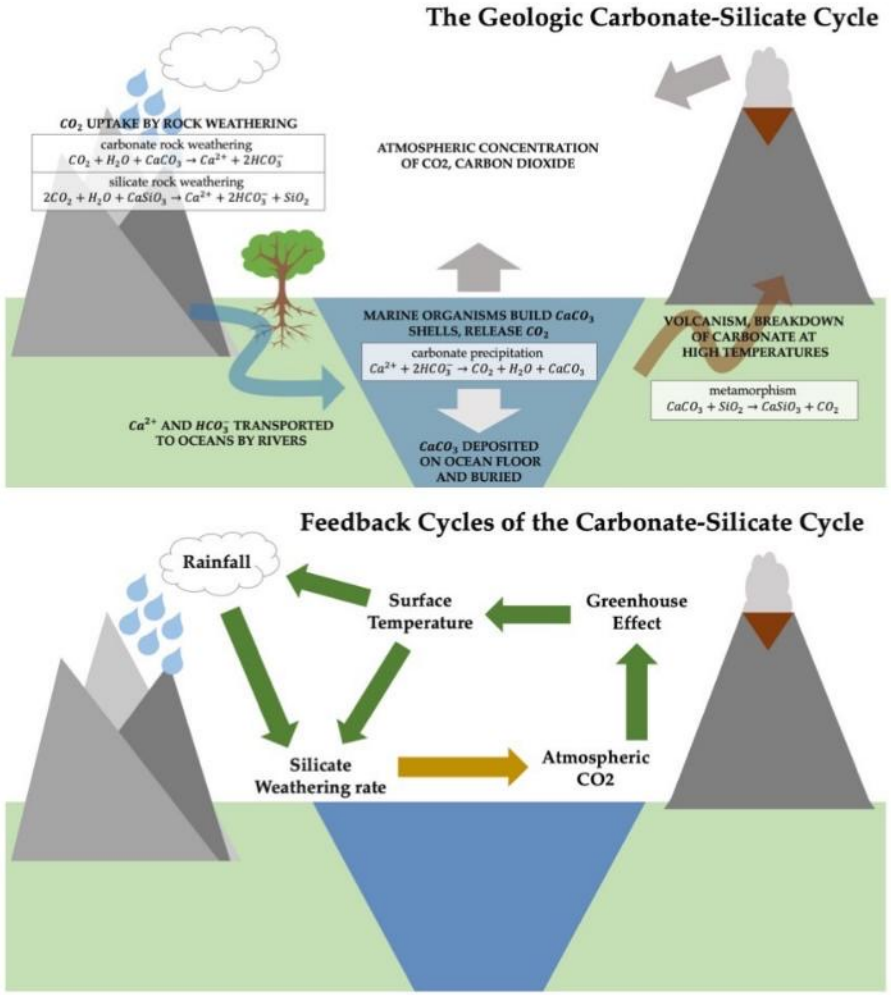


Ocean liming: limestone is calcined and the lime added to seawater

"The Process of Ocean Liming". Sparklingicee. CC BY-SA 4.0. Wikimedia Commons, reused under the licence stated.
https://commons.wikimedia.org/wiki/File:The_Process_of_Ocean_Liming.jpg

Enhanced weathering

Speeding up the silicate weathering that already regulates CO_2 on geological timescales

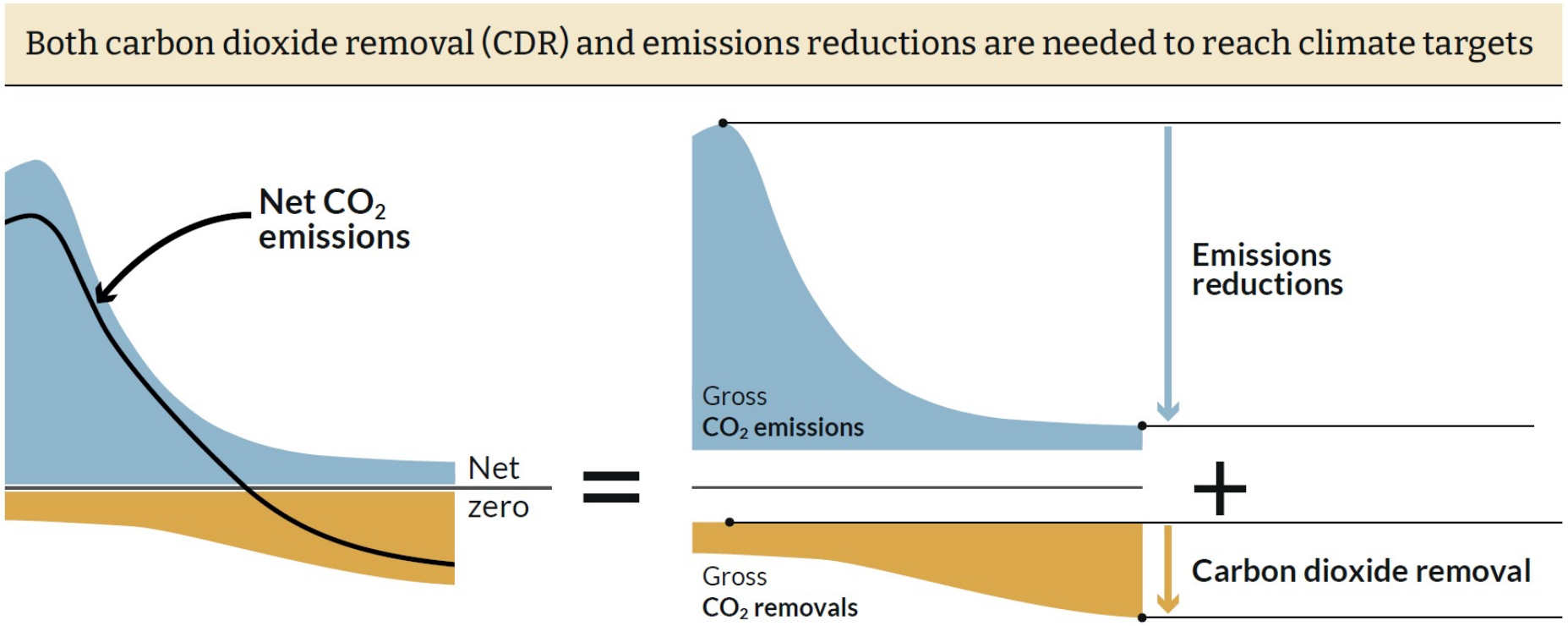


The carbonate–silicate cycle, the natural process being accelerated

"Carbon-Slicate Cycle Feedbacks". Gretashum. CC BY-SA 4.0. Wikimedia Commons, reused under the licence stated.
https://commons.wikimedia.org/wiki/File:Carbon-Slicate_Cycle_Feedbacks.jpg

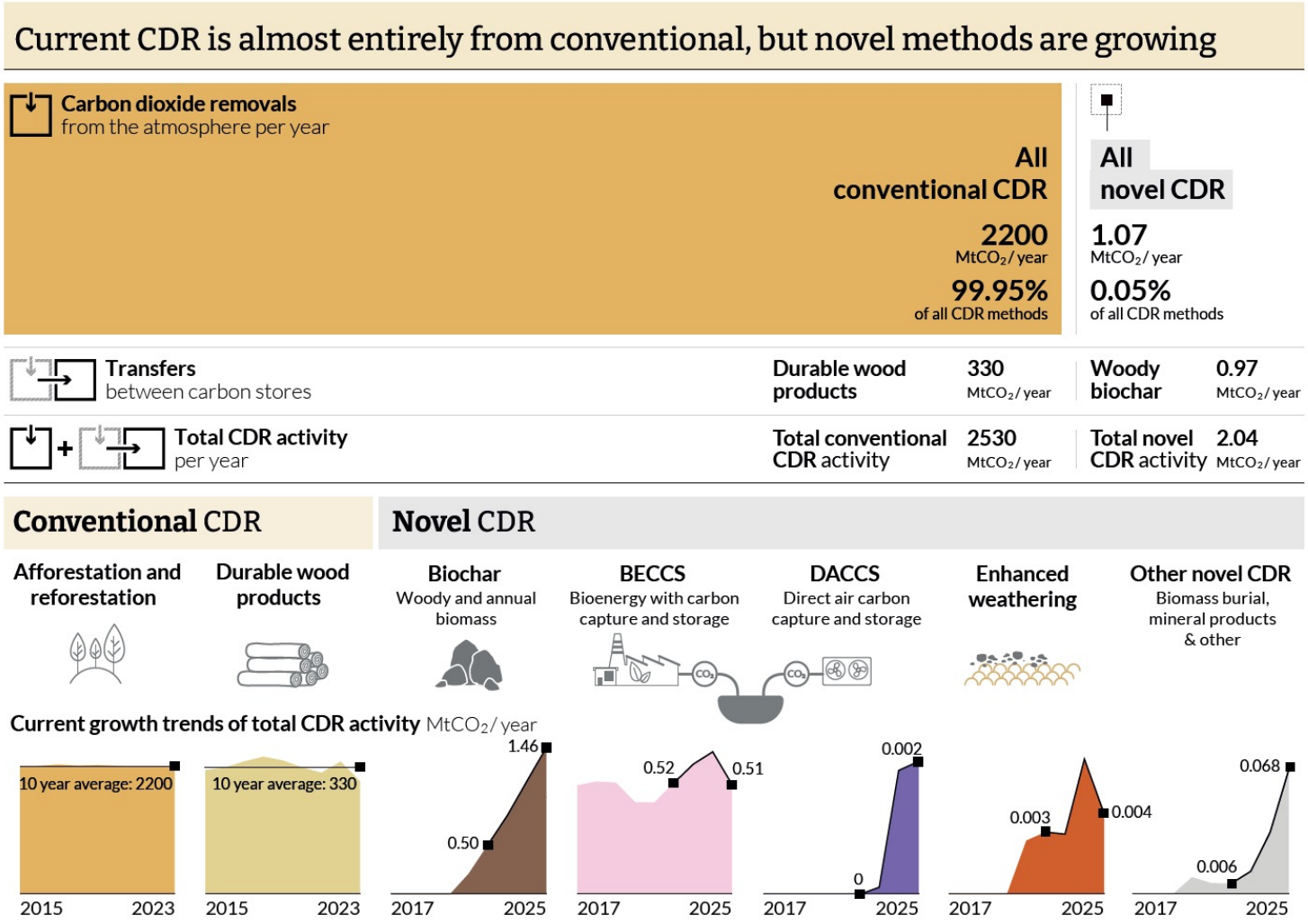
Emission reductions are essential, but CDR is needed too (at an uncertain scale)

- Edwards et al. (2026) State of CDR 3rd edition



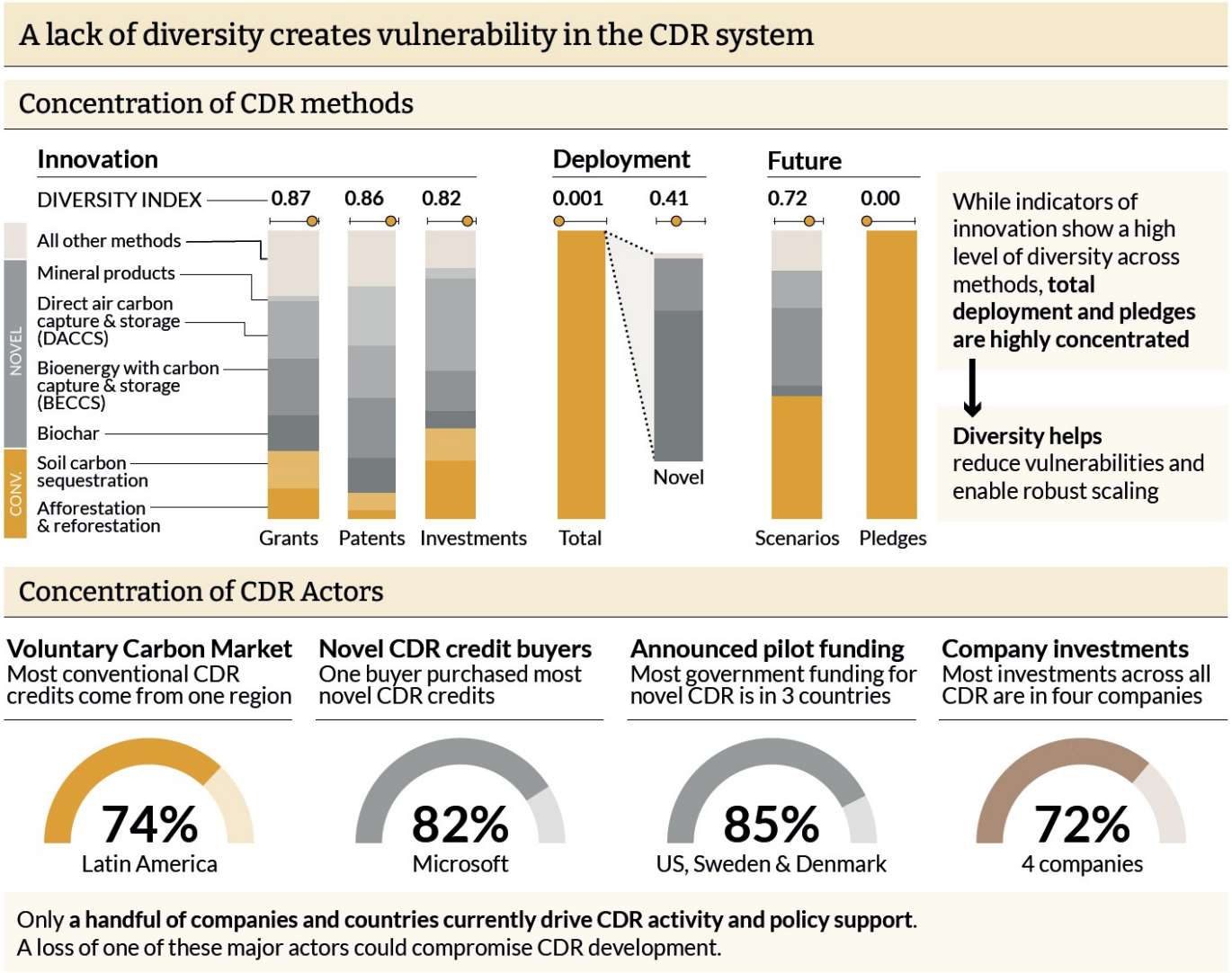
CDR today is mostly afforestation/reforestation

- Edwards et al. (2026) State of CDR 3rd edition



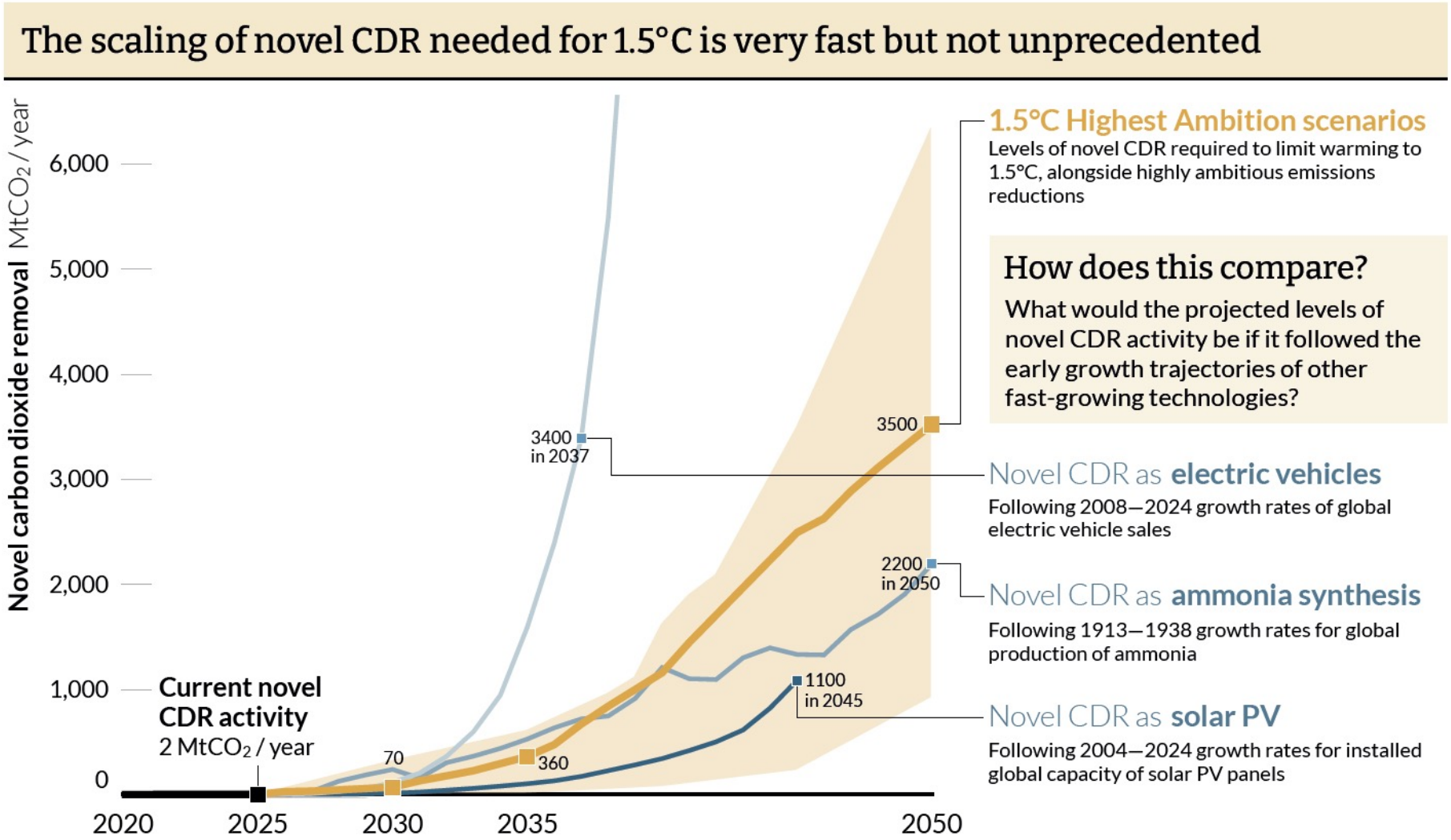
Today's CDR rests on the efforts of a small number of actors

- Edwards et al. (2026) State of CDR 3rd edition



CDR has to scale up extremely fast — but that is not without historical precedent

- Edwards et al. (2026) State of CDR 3rd edition



How to connect science and policy

Responsible innovation

- Principles have been discussed in many venues

- AGU (American Geophysical Union, the world's largest society in the Earth and planetary sciences)
  Ethical Framework Principles for Climate Intervention Research
  - ✓ Principle 1: Responsible research
  - ✓ Principle 2: Holistic climate justice
  - ✓ Principle 3: Inclusive public participation
  - ✓ Principle 4: Transparency
  - ✓ Principle 5: Informed governance

Intergovernmental Panel on Climate Change (IPCC)

- Created in 1988 by the World Meteorological Organization and UNEP
  - ✓ Seen through science and technology studies, a boundary organization
  - ✓ Policy-relevant, not policy-prescriptive

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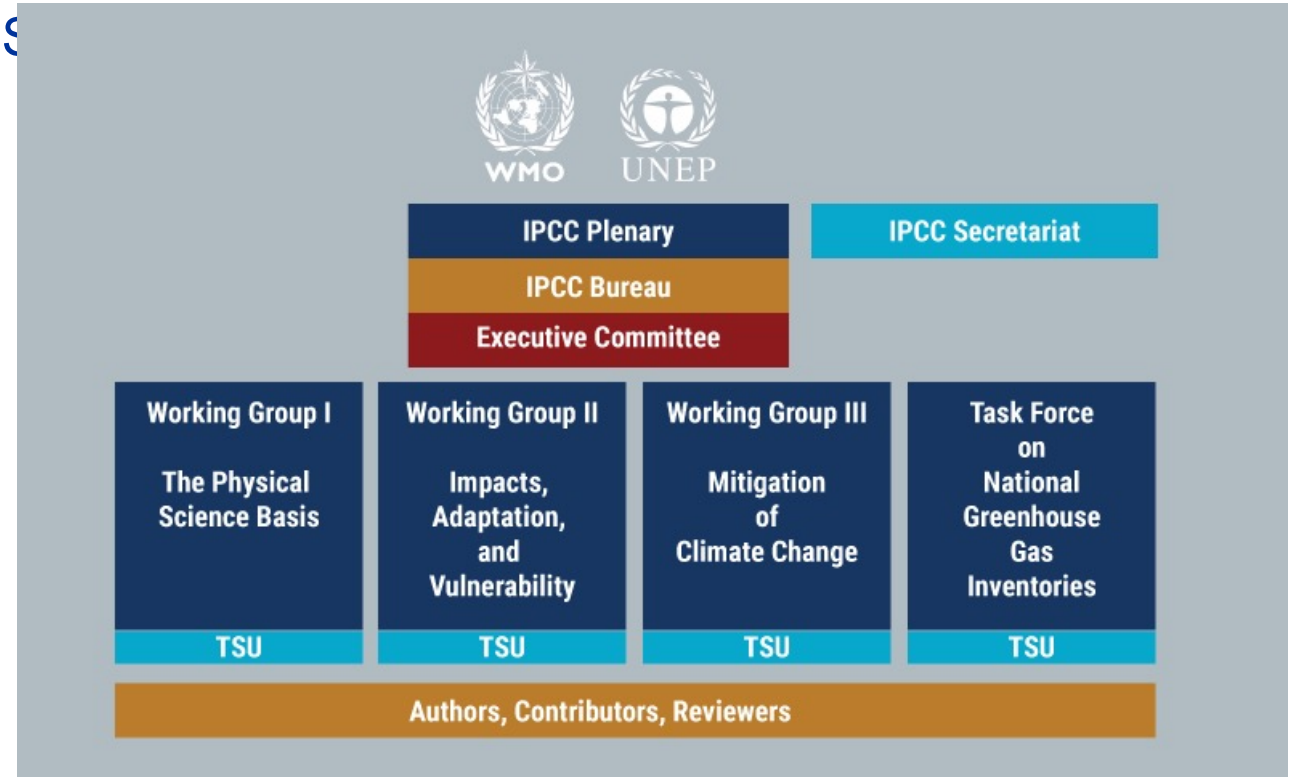

Intergovernmental Panel on Climate Change (IPCC)

- At first it mattered most for establishing the science of global warming; today its role in presenting solutions is becoming the important one

- The main report (which almost nobody outside the expert community reads) is thoroughly scientific

- The Summary for Policymakers is in effect a political document
  - ✓ At the plenary it is projected line by line and governments comment on it
  - ✓ Negotiations sometimes run through the night https://www.smh.com.au/environment/climate-change/next-decade-critical-perils-mount-at-1-5-degrees-of-warming-says-ipcc-20181008-p508ci.html

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