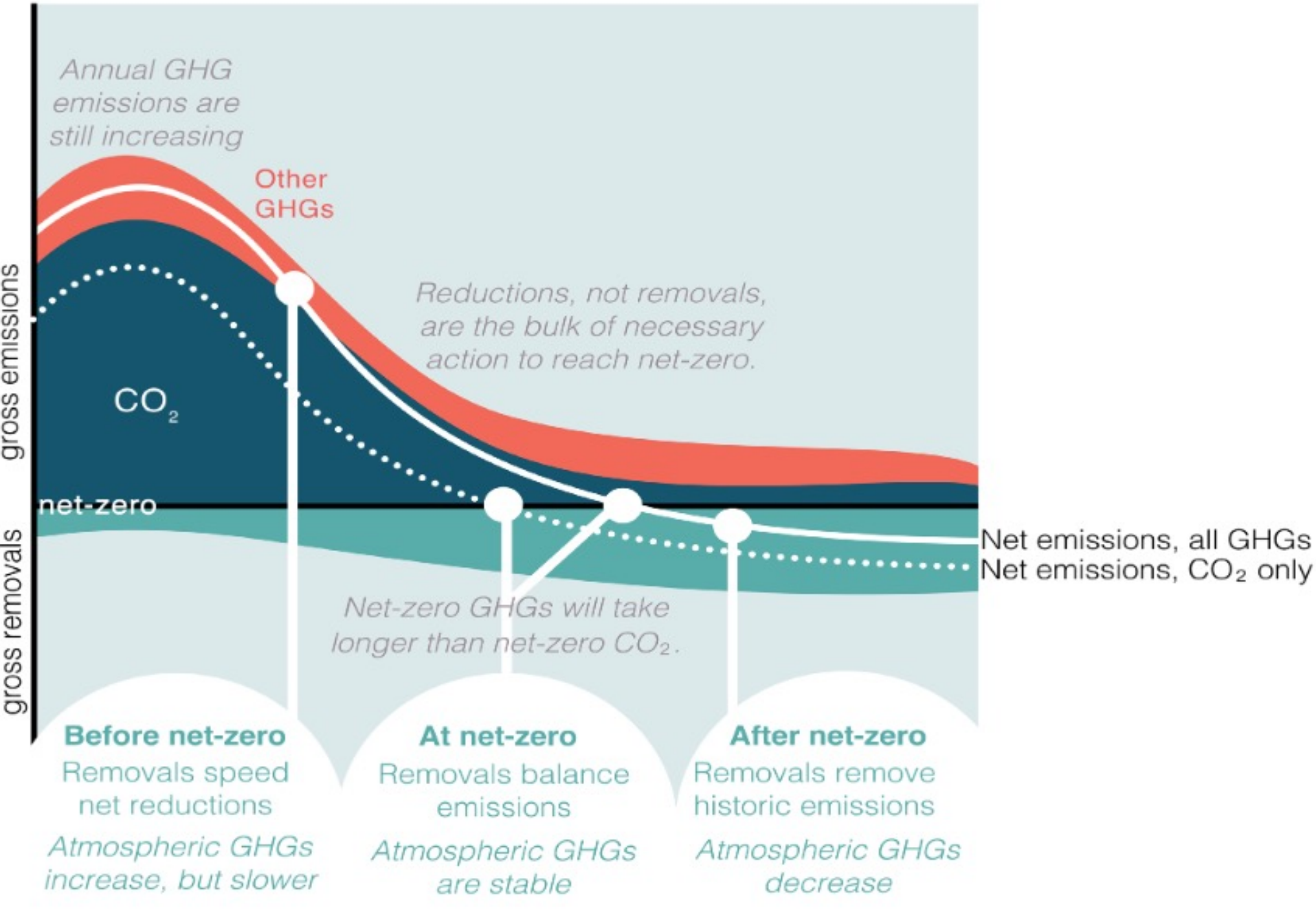
Putting the NET in net-zero:

a field guide to

Negative Emission Technologies

11 May 2023



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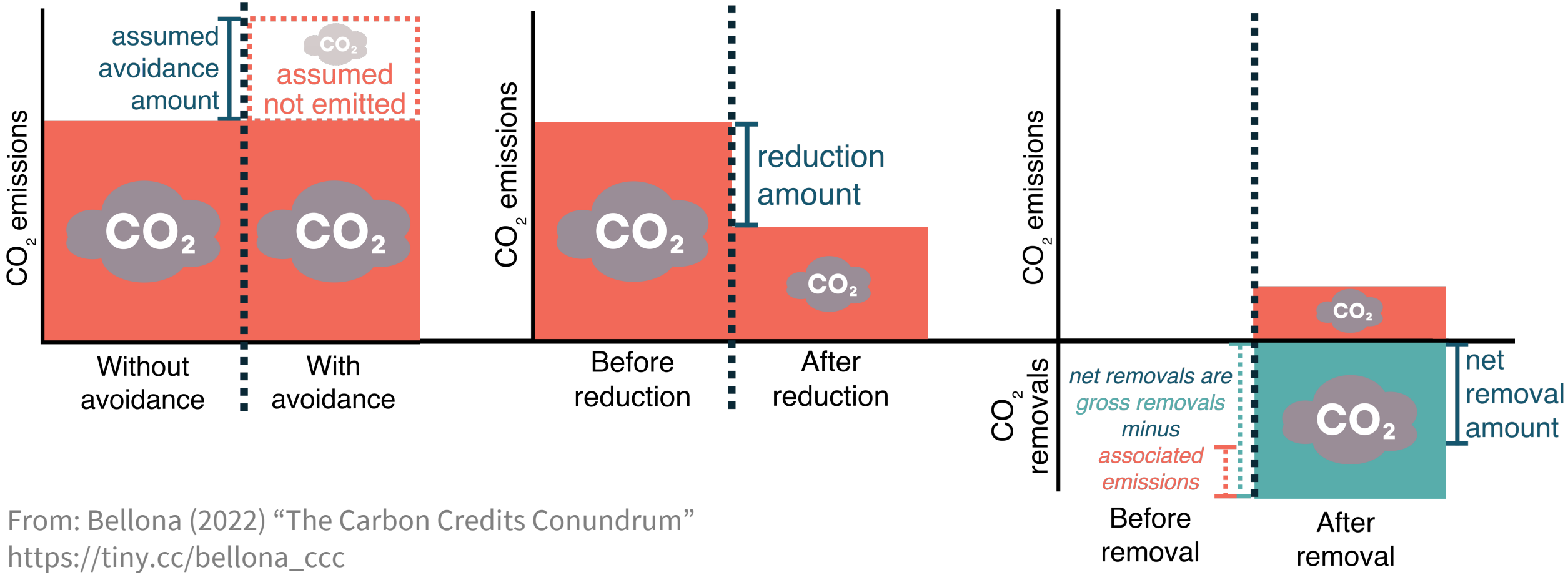
Carbon Dioxide Removal is unavoidable (if we want to meet our climate targets)

Three distinct types of action

CO_2 Avoidance:
Emitting less CO_2 than an alternate scenario.

CO_2 Reduction:
Emtting less CO_2 than in the past.

CO_2 Removal:
Physically extracting and permanently storing CO_2 out of the atmosphere.



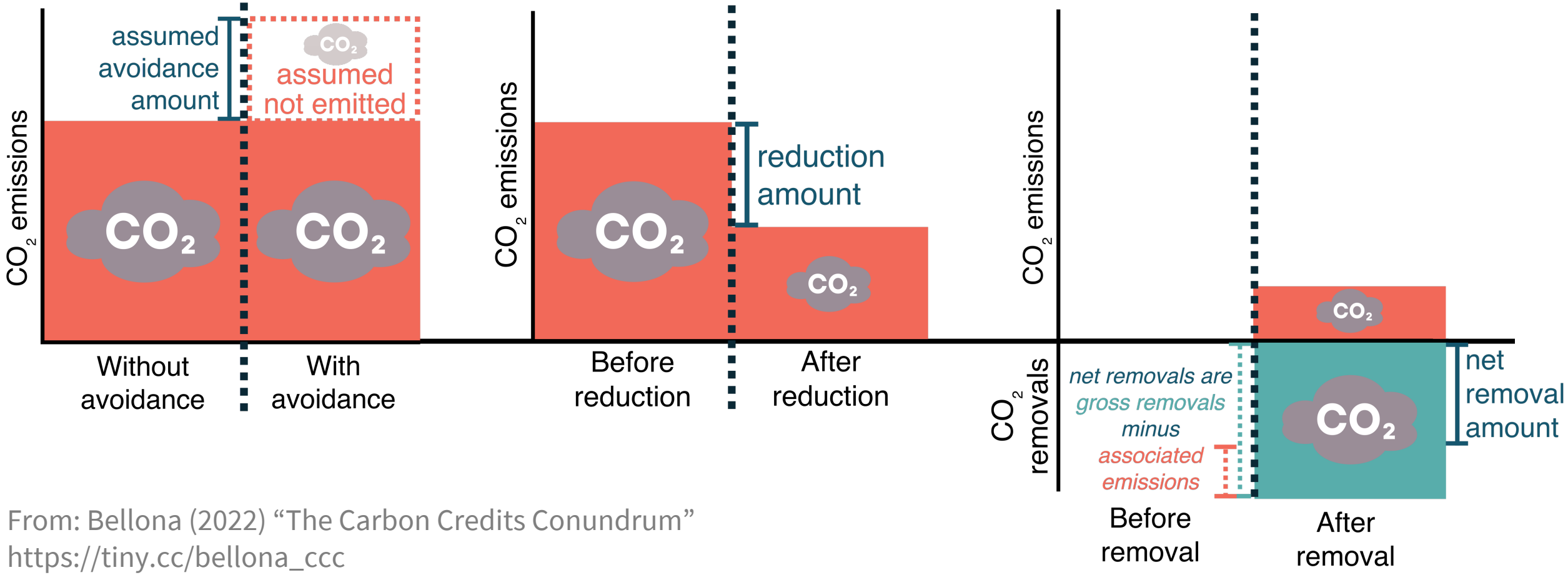
From: Bellona (2022) "The Carbon Credits Conundrum"
https://tiny.cc/bellona_ccc

Three distinct types of results

CO_2 Avoidance:
Atmospheric CO_2 doesn't increase even faster than it already is

CO_2 Reduction:
Atmospheric CO_2 increases less quickly than in the past
(or even stops increasing)

CO_2 Removal:
Atmospheric CO_2 decreases



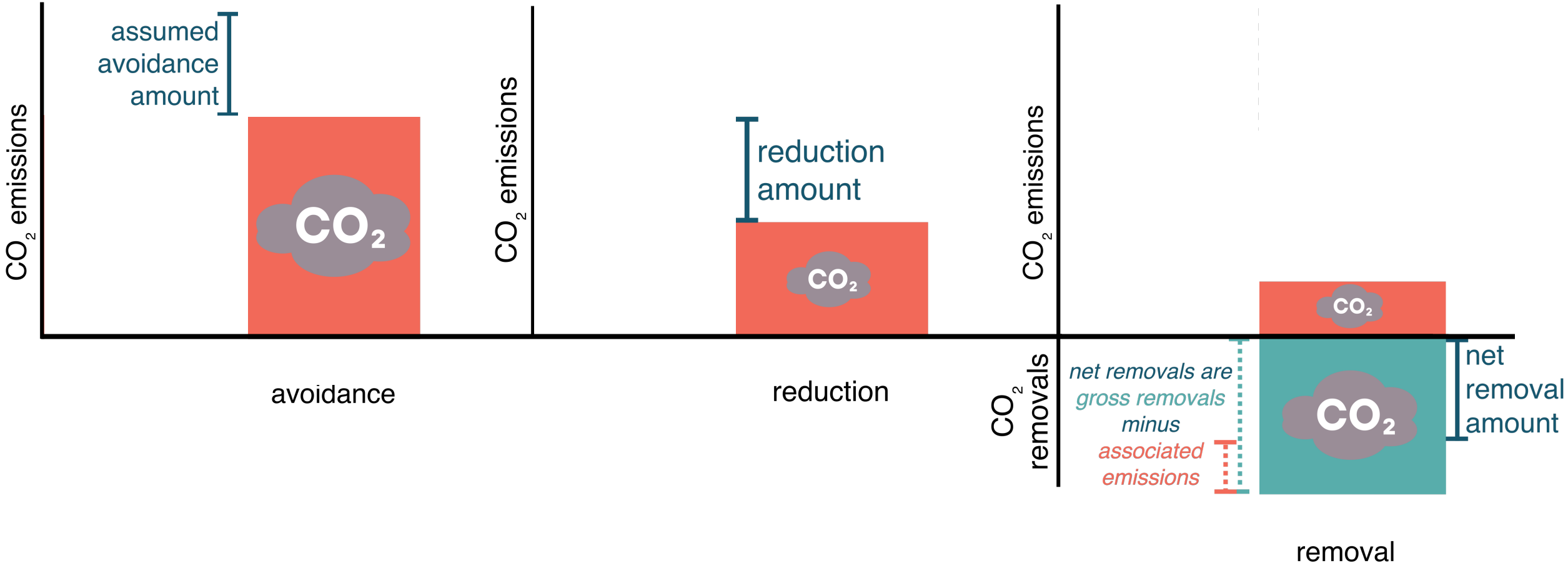
From: Bellona (2022) "The Carbon Credits Conundrum"
https://tiny.cc/bellona_ccc

Only one that measures a physical flow

CO_2 Avoidance:
measures a **"non-emission"** in *t CO_2 assumed to be avoided*

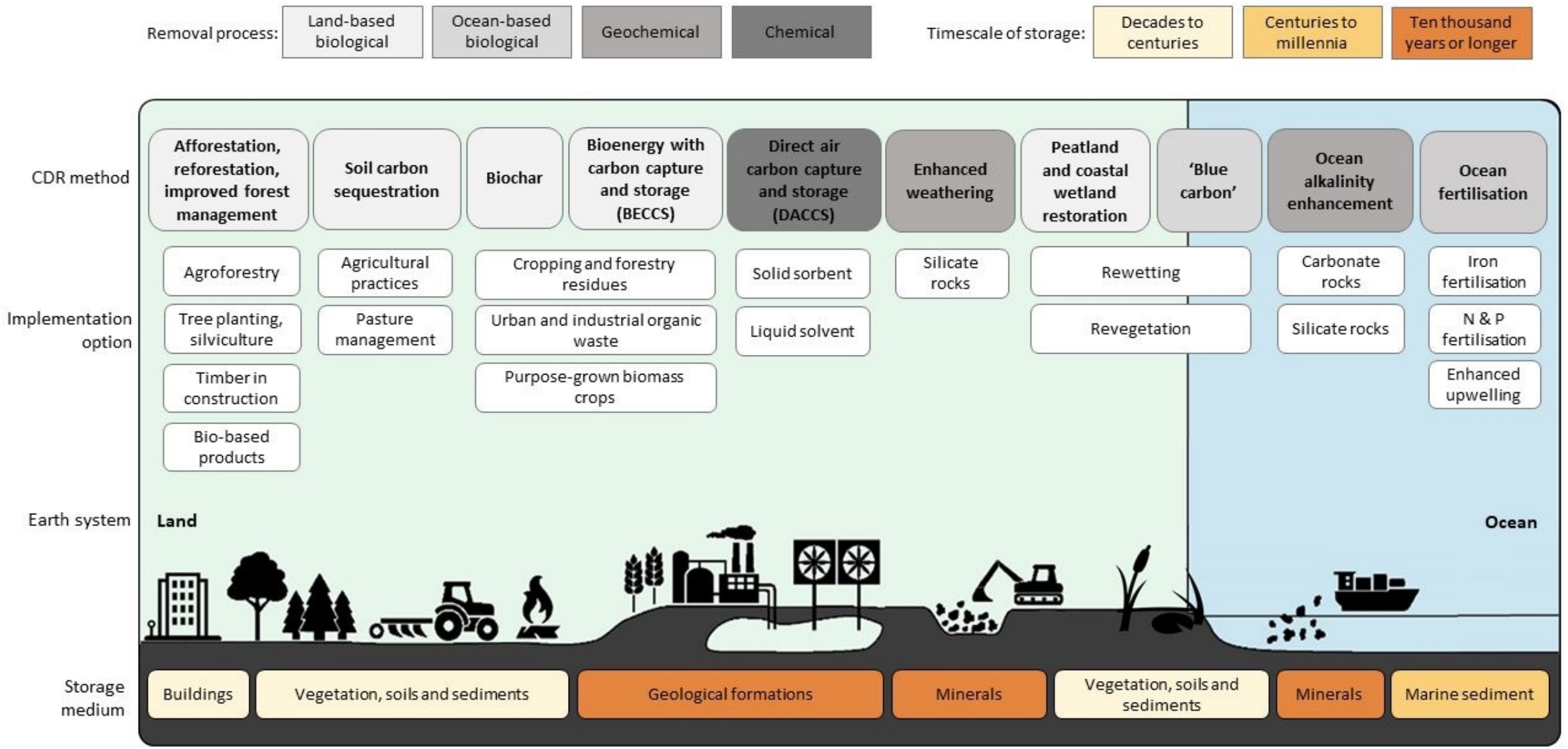
CO_2 Reduction:
measures a **"non-emission"** in *t CO_2 less than before*

CO_2 Removal:
measures **physical flows** in *t CO_2 removed from the atmsophere minus t CO_2 associated emissions*



When does a NET result in a net removal?

The “Source-Sink-System” method



Source: IPCC AR6 WGIII, Chapter 12 (Box 8, Figure 1)

Source: Where does the CO_2 come from?

1. CO_2 is **physically extracted** from the atmosphere.

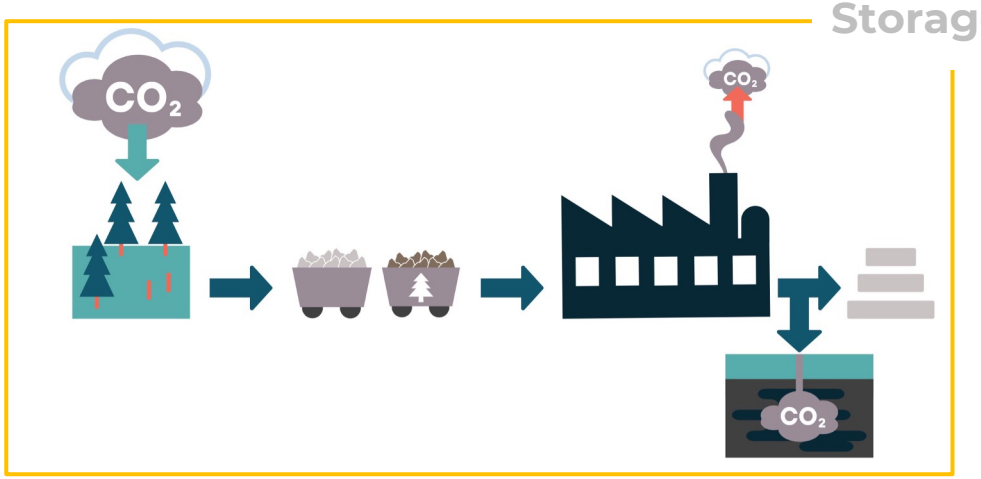
Biomass + CCS

Extraction by biomass

Use by humans

Recapture by Chemicals

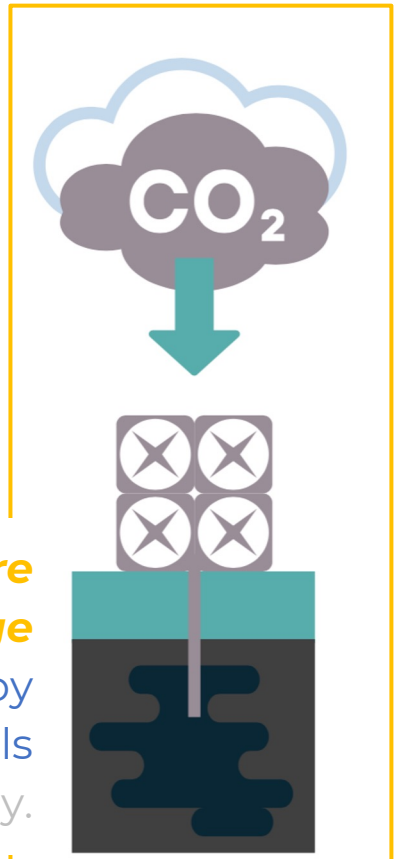
Storage in geology.



Direct Air Capture + Storage

Extraction by chemicals

Storage in geology.

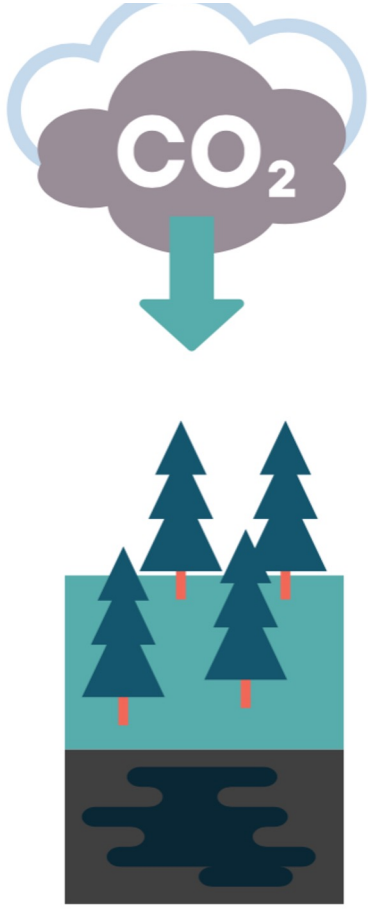


Afforestation

Extraction by biomass

Storage in biomass.

Ongoing management.



How to get CO_2 out of the atmosphere

- **Photosynthesis** — Plants being plants

  $6CO_2 + 6H_2O \rightarrow C6H_{12}O_6 + 6O_2$

- **Mineral Weathering** — Some rocks will dissolve when exposed to the water and CO_2 in the atmosphere

  $CO_2 + 3\ H_2O + CaSiO_3 \rightarrow Ca_2+ + 2HCO_3^- + H_4SiO_4$

- **Carbonation** — Some minerals absorb CO_2 into themselves

  e.g., $CaO + CO_2 \rightarrow CaCO_3$

- **Chemical Absorption** — Some chemicals absorb CO_2 into themselves

  e.g., $R_1R_2NH + CO_2(aq) \rightarrow R_1R_2NH^+CO_2^-$

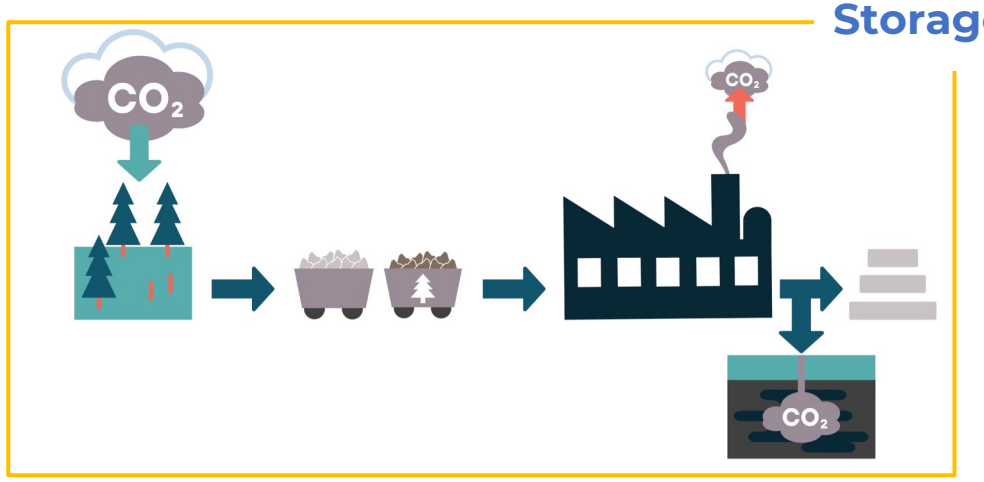
- **Air-sea flux** — Surface ocean absorbs CO_2 based on relative partial pressure of CO_2 in the air vs in the sea

Sink: Where does the CO_2 go?

1. CO_2 is **physically extracted** from the atmosphere.
2. The extracted atmospheric CO_2 is **permanently stored**.

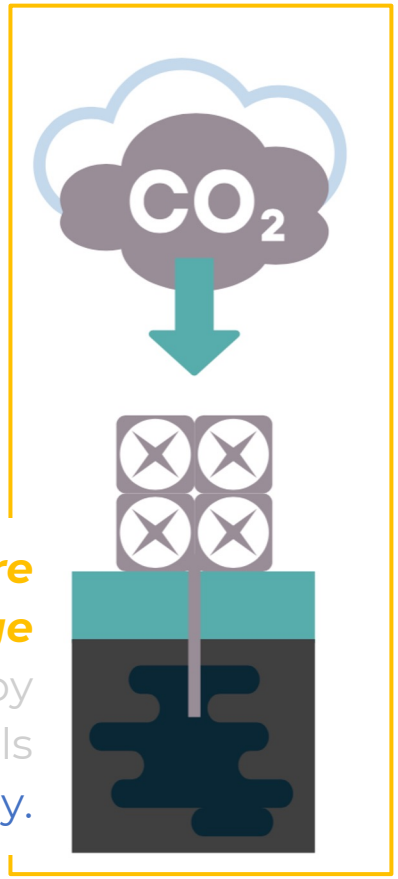
Biomass + CCS

Extraction by biomass
Use by humans
Recapture by Chemicals
Storage in geology.



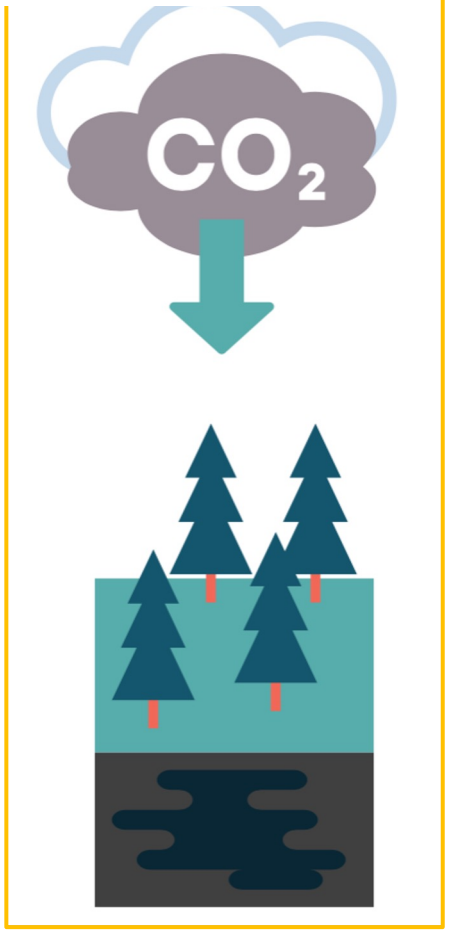
Direct Air Capture + Storage

Extraction by chemicals
Storage in geology.



Afforestation

Extraction by biomass
Storage in biomass.
Ongoing management.



Where can we put CO_2?

- **Geosphere** — Disused oil and gas wells, saline aquifers, basalt formations
- **Biosphere**— Forests, soils, rooted near-shore biomass
- **Hydrosphere** — Ocean fertilization and liming, biomass sinking, CO_2 sinking
- **Anthroposphere** — Letting CO_2 hang out (temporarily) in human society, e.g., in wood products, durable plastics, concrete, biochar
- **Atmosphere**— via direct use (e.g., greenhouses) or conversion to fuels, short-lived chemicals, or short-lived minerals

Does this NET result in permanent removals?

(and under what circumstances is it still useful if it doesn't)

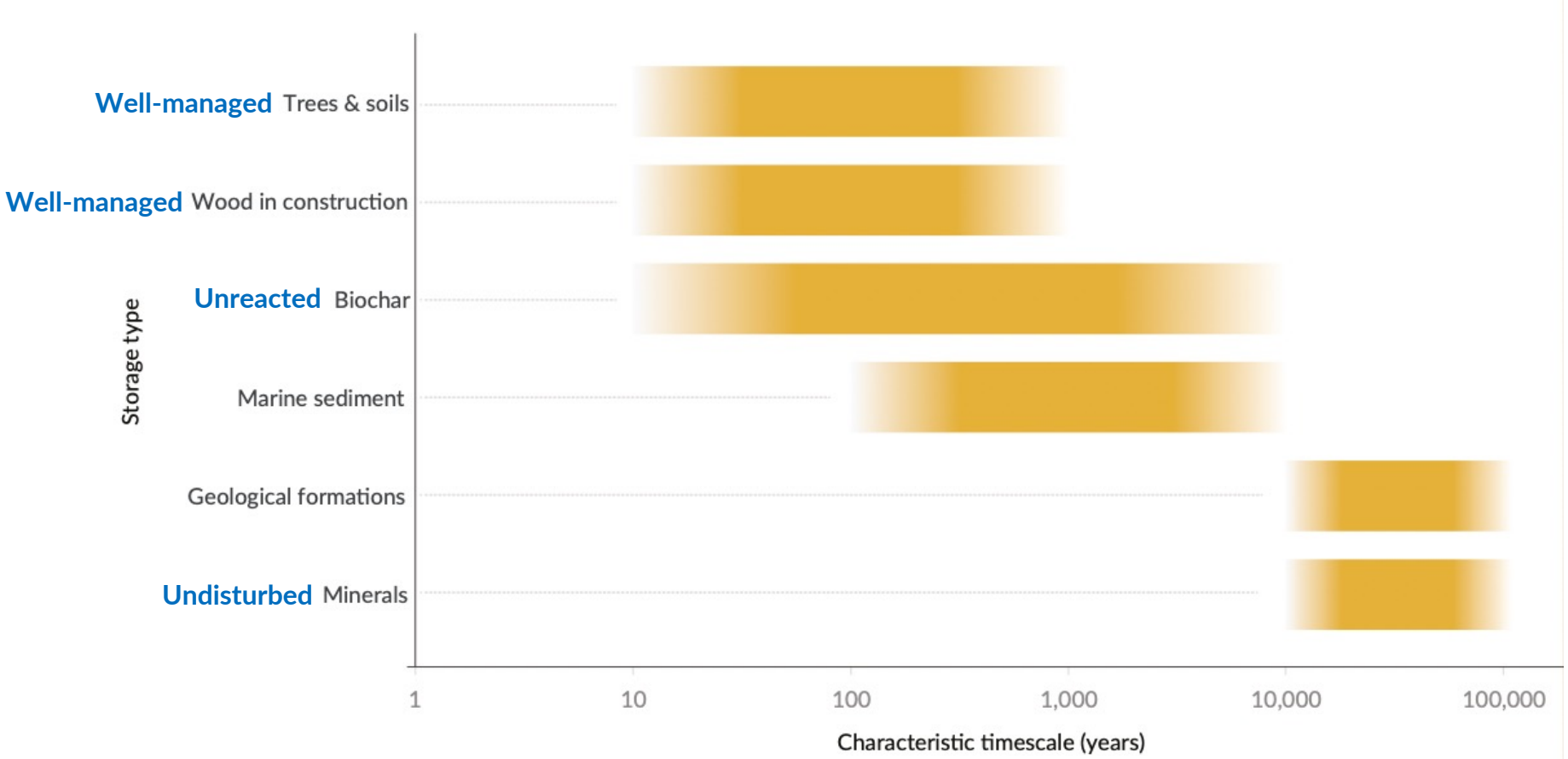


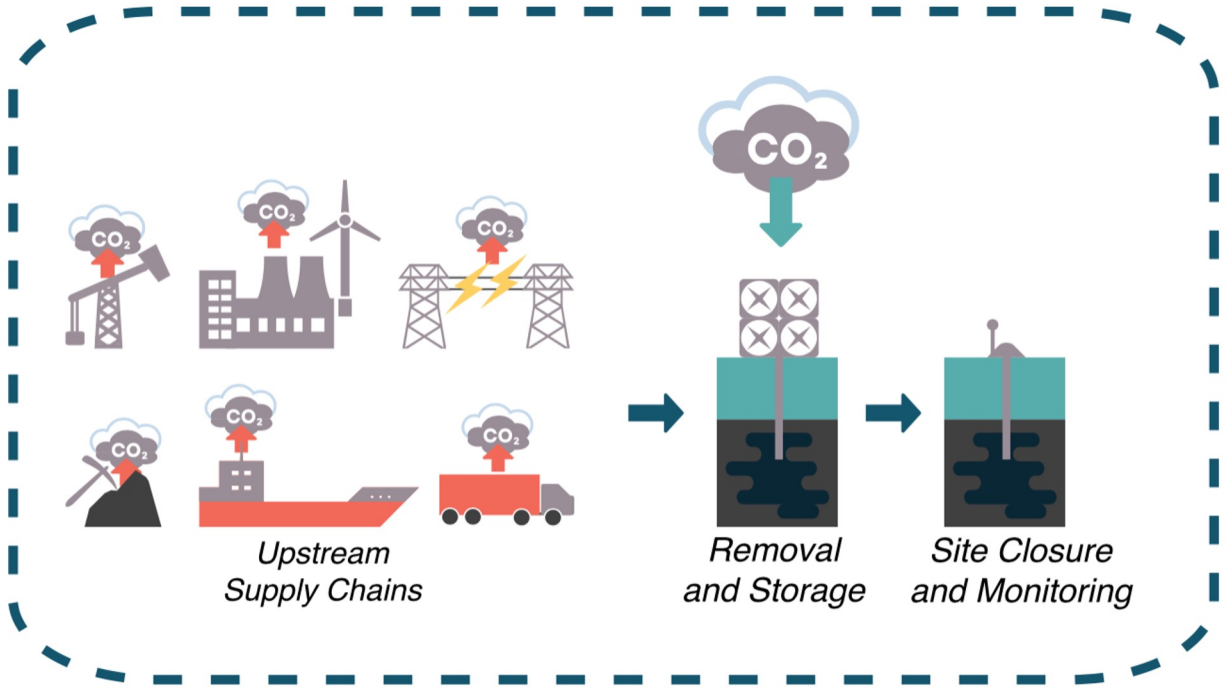
Figure 1.3. *The durability of different carbon storage pools ranges from decades to tens of millennia. Note that these timescales are indicative, assuming no premature disturbance. Source: IPCC WG3 AR6 Chapters 7 & 12*[13,19].

Where can we put CO_2?

- **Geosphere** — **Permanent** when well-managed, risk decreases over time
- **Biosphere**— Requires **perpetual upkeep**, risk of creating a "carbon timebomb", especially as climate change increases risks
- **Hydrosphere** —Currently **impossible to verify** or monitor; high uncertainty of climate effect
- **Anthroposphere** — **Final fate uncertain**; length of storage uncertain; may prove unmonitorable
- **Atmosphere**— **Never results in a removal**

System: What happens between, before, and after source and sink?

1. CO_2 is **physically extracted** from the atmosphere.
2. The extracted atmospheric CO_2 is **permanently stored**.
3. All greenhouse gas emissions associated with the removal and storage processes are comprehensively estimated and included.



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Actual system boundaries

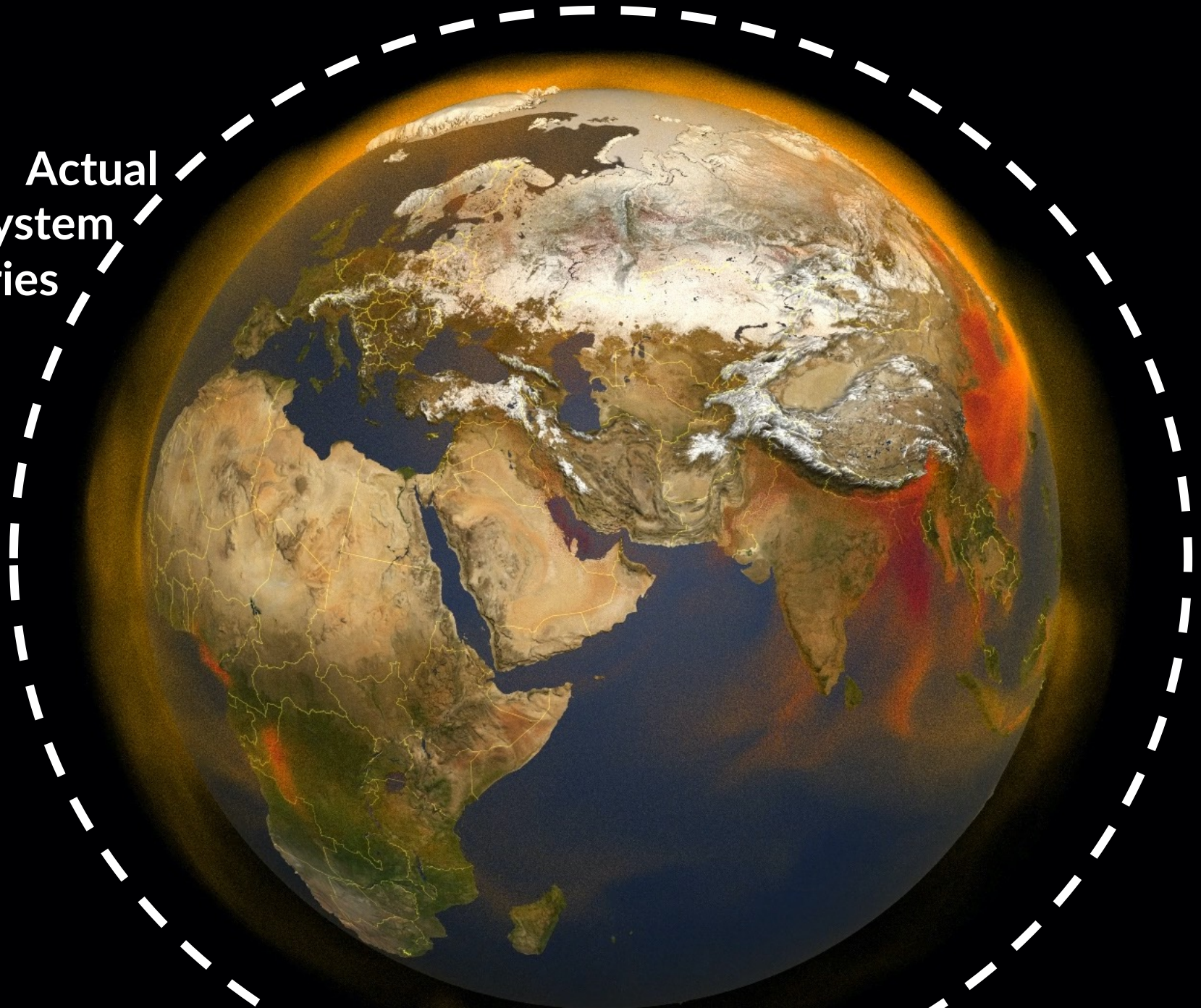


Image Credit: NASA/Scientific Visualization Studio

What we talk about when we talk about systems

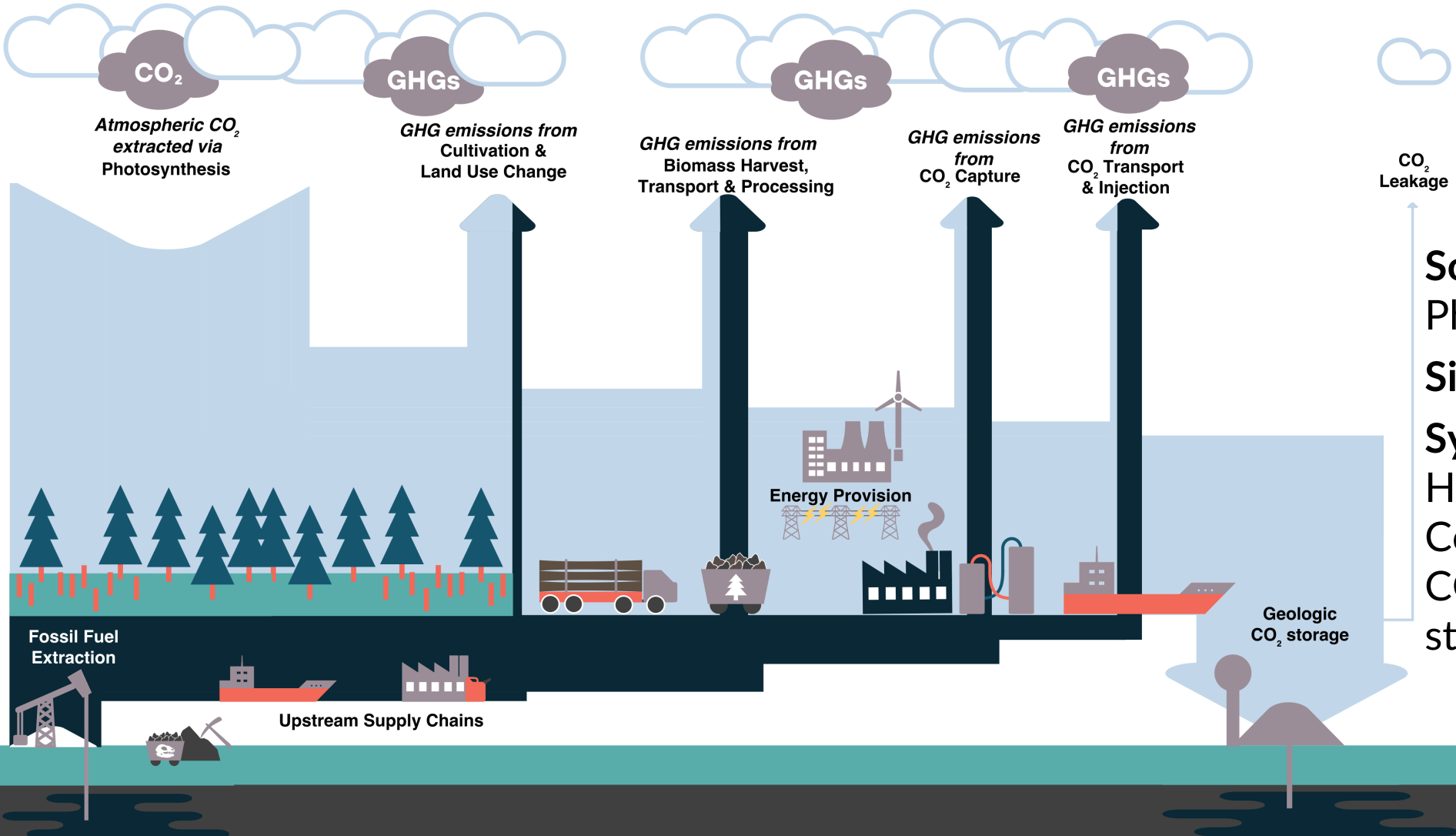
Direct System Impacts, e.g.,

- CO_2 use and losses
- Transport
- Energy generation
- Input Production
- Infrastructure
- Resource extraction
- Land Use
- Supply Chains

Indirect System Impacts, e.g.,

- Competition for resources
- Indirect land use change
- Changes in energy production mix
- Changes in demand
- Changes in behaviour

Biomass with Carbon Capture and Storage



Source: Atmosphere via Photosynthesis

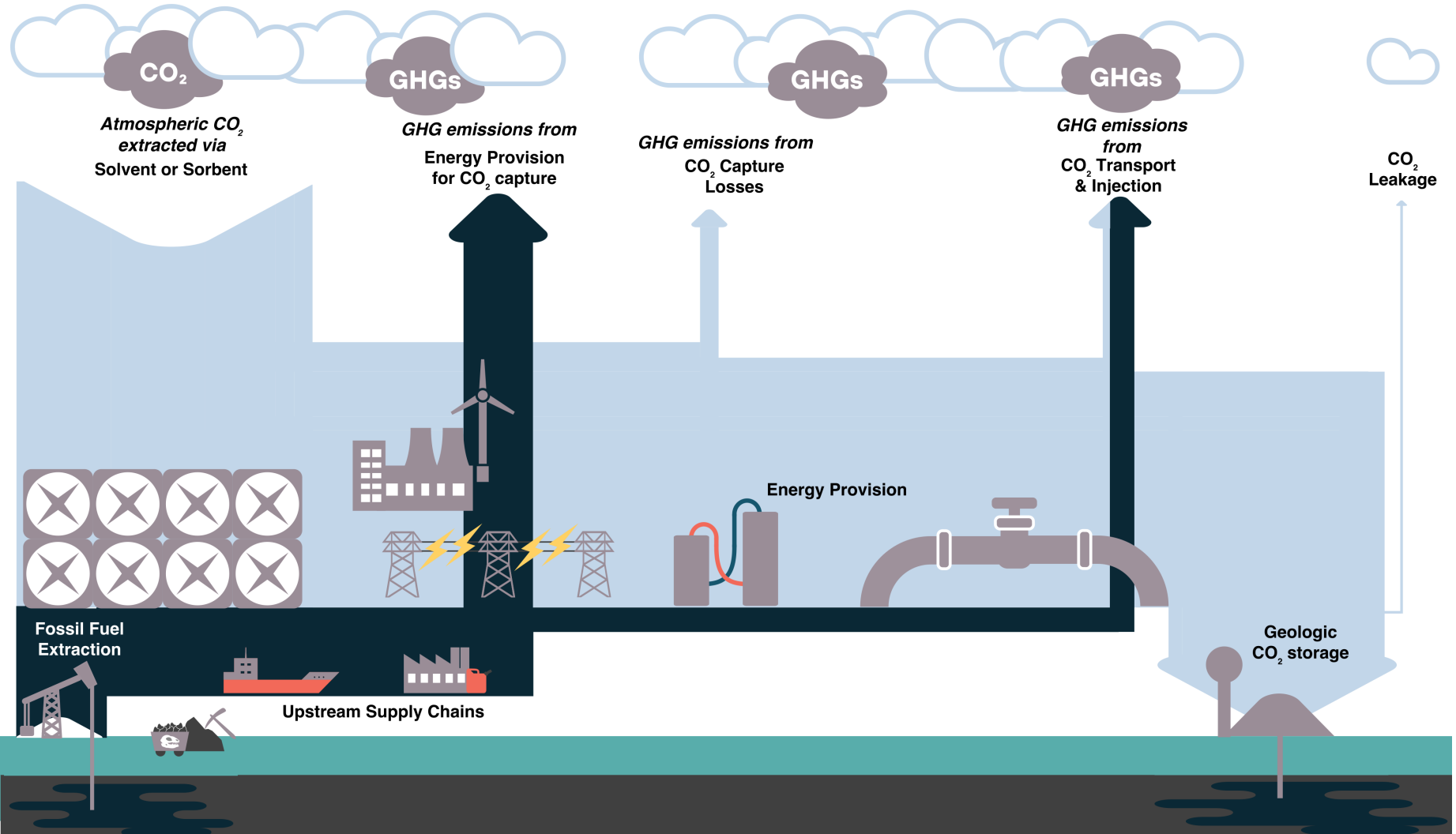
Sink: Geologic Storage

System: Biomass Cultivation, Harvest, Transport, Conversion and Use CO_2 capture, transport, and storage

What industries already emit biogenic CO_2?

- Ethanol Production
- Alcohol Production
- Biogas Upgrading
- Pulp and Paper Production
- Some chemical production (e.g. biomethanol)
- Combustion of (partially) biogenic waste for energy, e.g., in
  - CHP plants
  - Cement kilns
  - Waste incinerators
- Partial use in iron production in certain countries (e.g., Brazil)

Direct Air Carbon Capture and Storage



Source: Atmosphere via Sorbent or Solvent

Sink: Geologic Storage

System: Energy provision, Infrastructure, CO_2 capture, transport, and storage

How much energy are we talking about?

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Atmospheric CO_2 (0.04% CO_2)

8-10 GJ/t CO_2 extraction

Process CO_2 (10 – 20% CO_2)

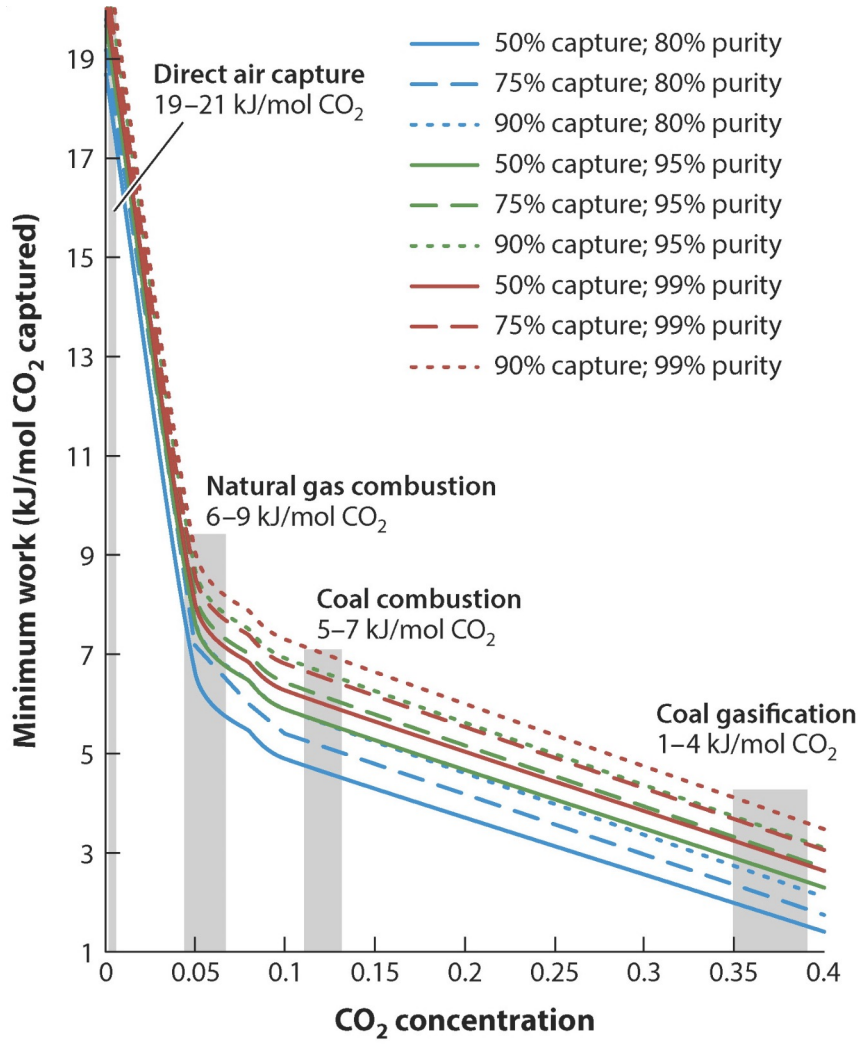
2-4 GJ/t CO_2 captured

(Current energy demand is approx. 10x the theoretical minimum)

10 GJ is enough to produce
1 tonne of steel or 3 tonnes of concrete

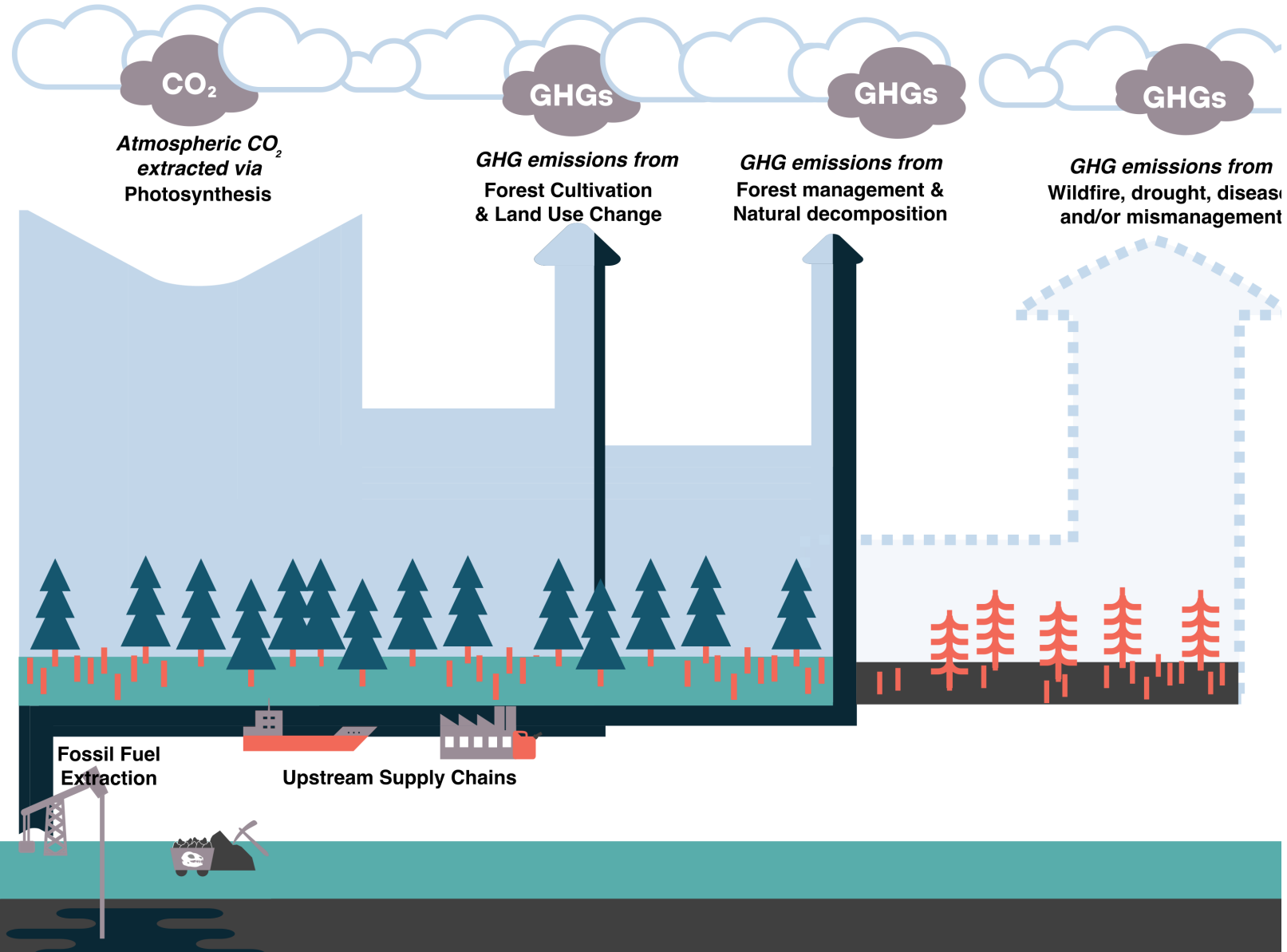
Burning 10 GJ to fossil fuels would emit:
Coal: 950 kg CO_2
Heavy Fuel Oil: 780 kg CO_2
Gas: 570 kg CO_2

So a lot of low-carbon energy is a must for DACCS to be carbon efficient.



Wilcox J, et al. 2014.
Annu. Rev. Chem. Biomol. Eng. 5:479–505

Afforestation



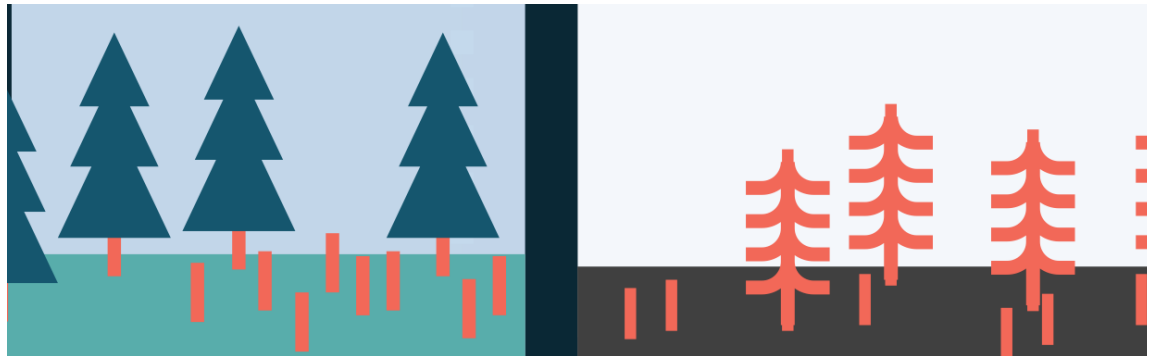
Source: Atmosphere via Photosynthesis

Sink: Standing biomass (with continuous management)

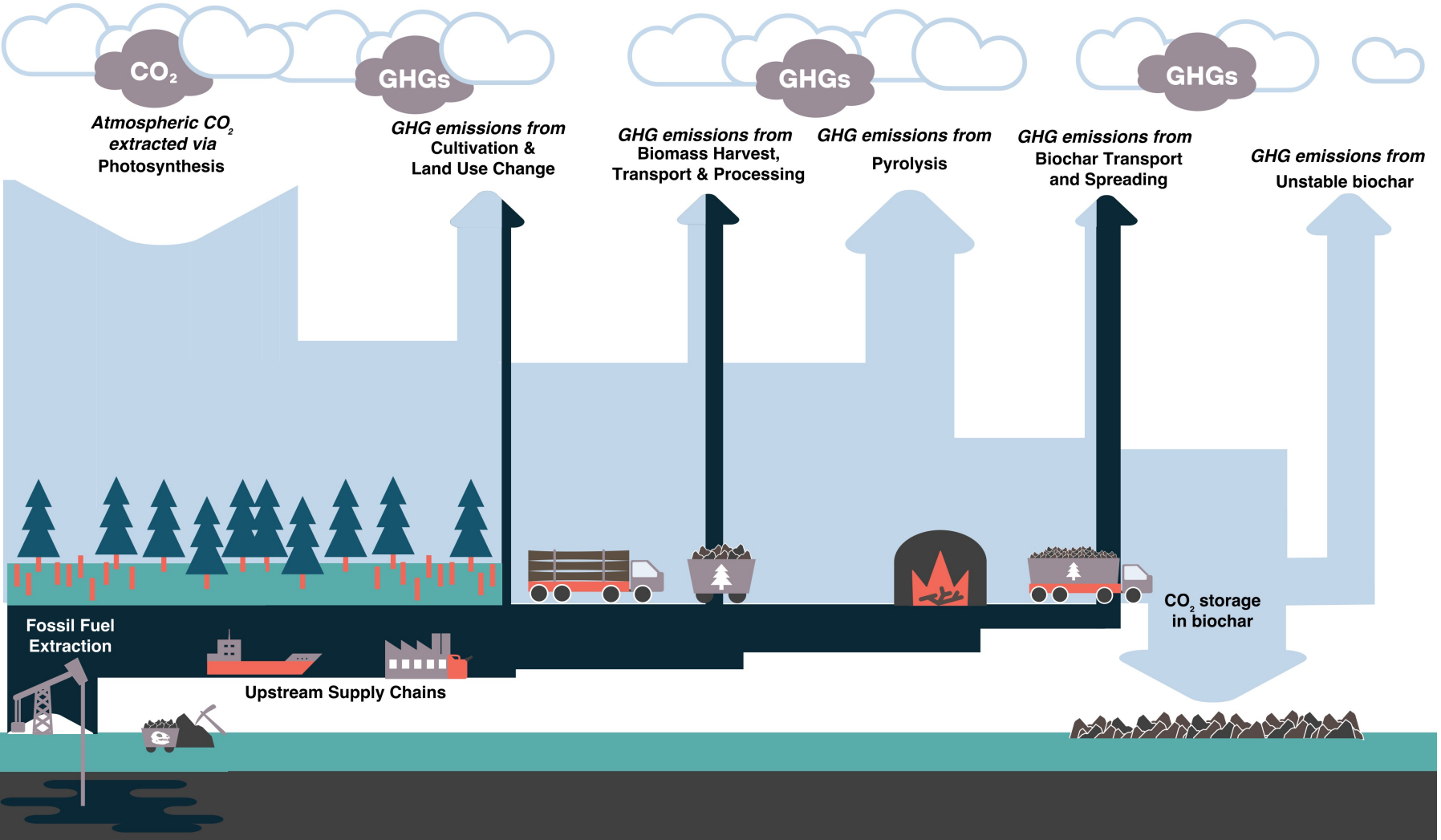
System: Land transformation, forest management, decomposition, deforestation risk

Some forest facts

- Optimising for carbon storage does not necessarily a good forest make
- Biomass growth is “S”-curved: first slow, then fast, then stops
- Forests have to be maintained in perpetuity, even after the sink saturates
- Climate change will increase stress on forests



Biochar

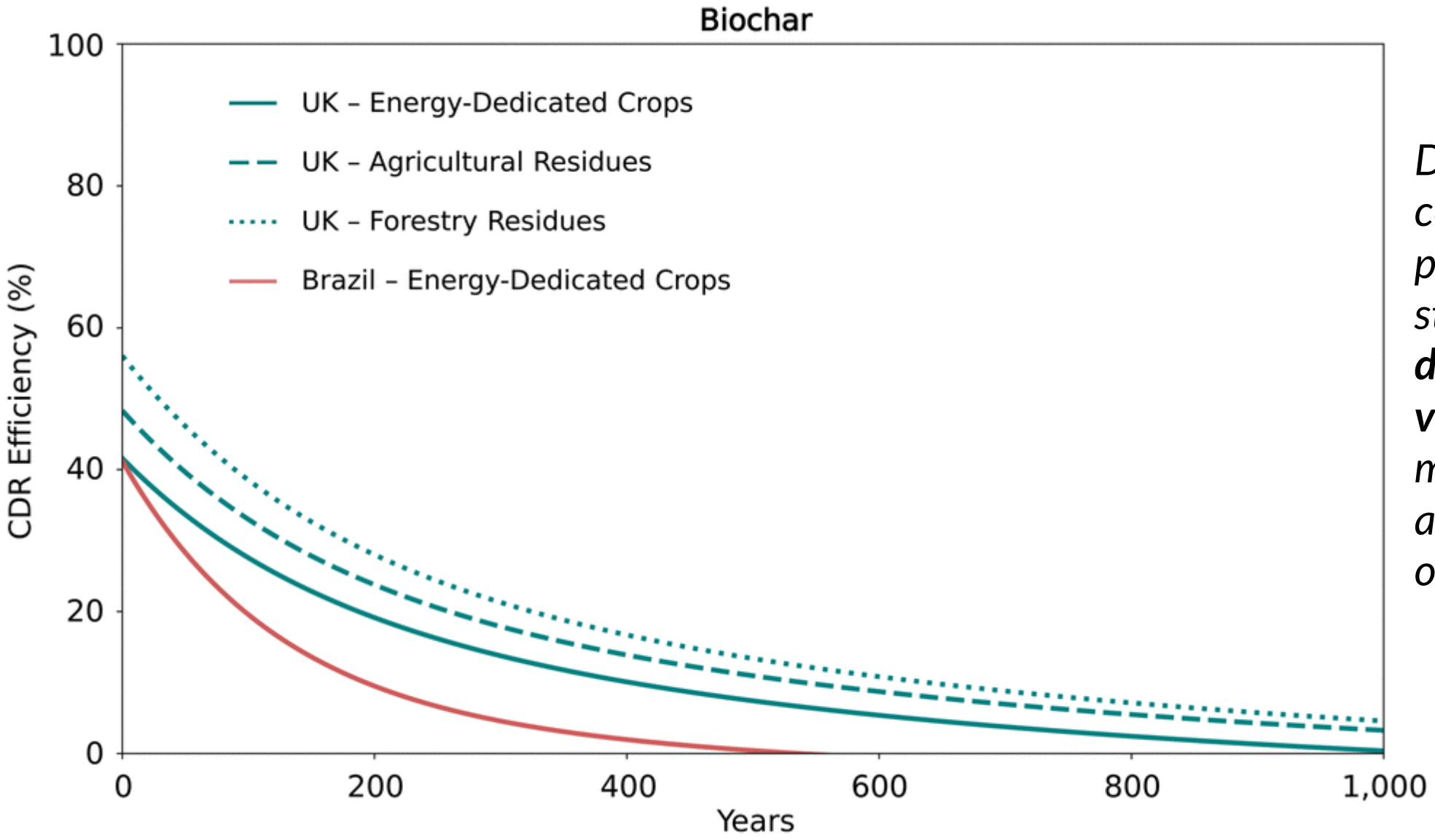


Source: Atmosphere via Photosynthesis

Sink: Pyrolysized biomass

System: Biomass Cultivation, Harvest, Transport,and Conversion; Pyrolysis;

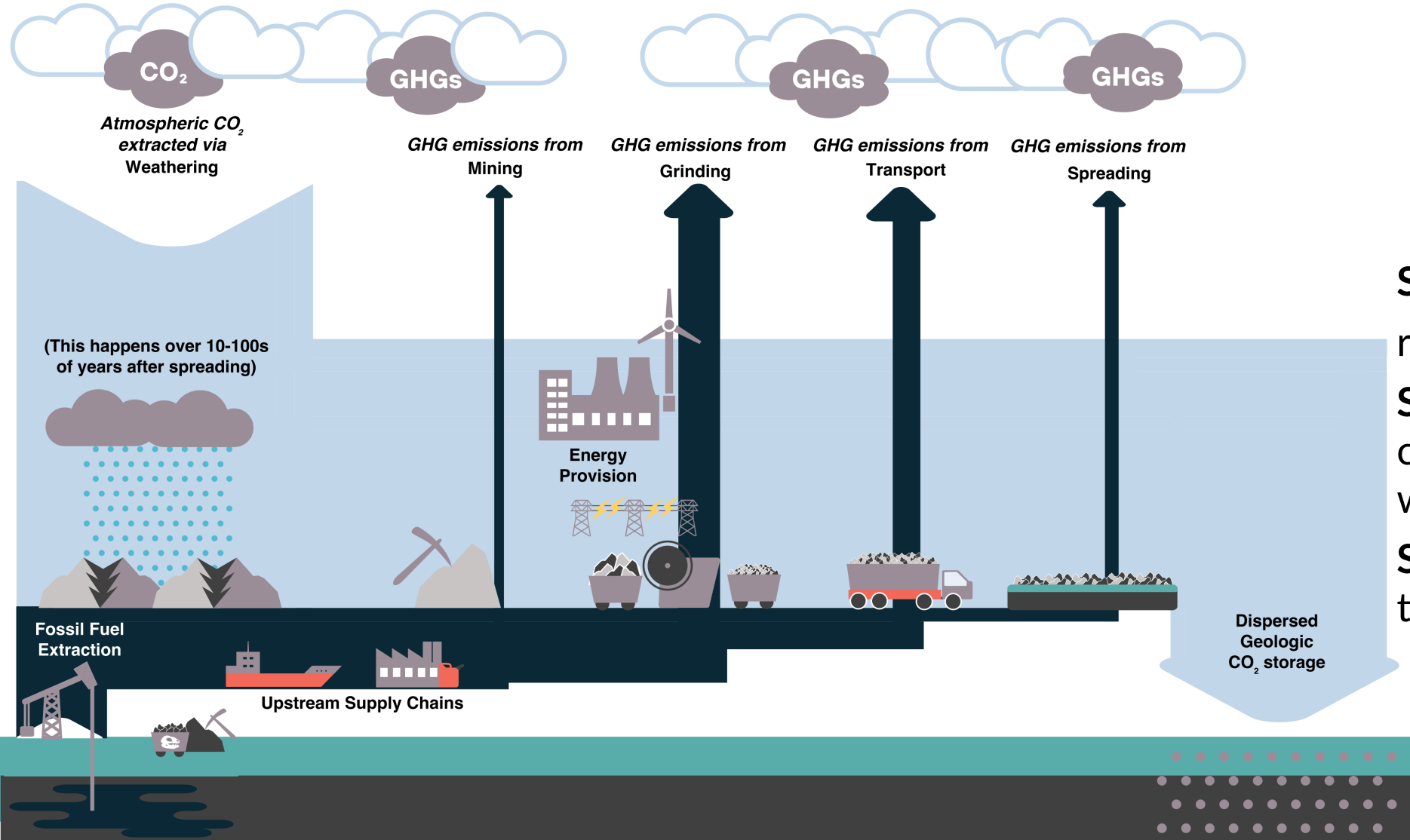
Biochar Transport, Spreading, and Degradation



Depending on the conditions of biochar production and storage, ***biochar decays over time at varying rates****—likely much faster if used as a soil amendment, as often proposed*

From: Chiquier et al 2022
DOI: 10.1039/D2EE01021F

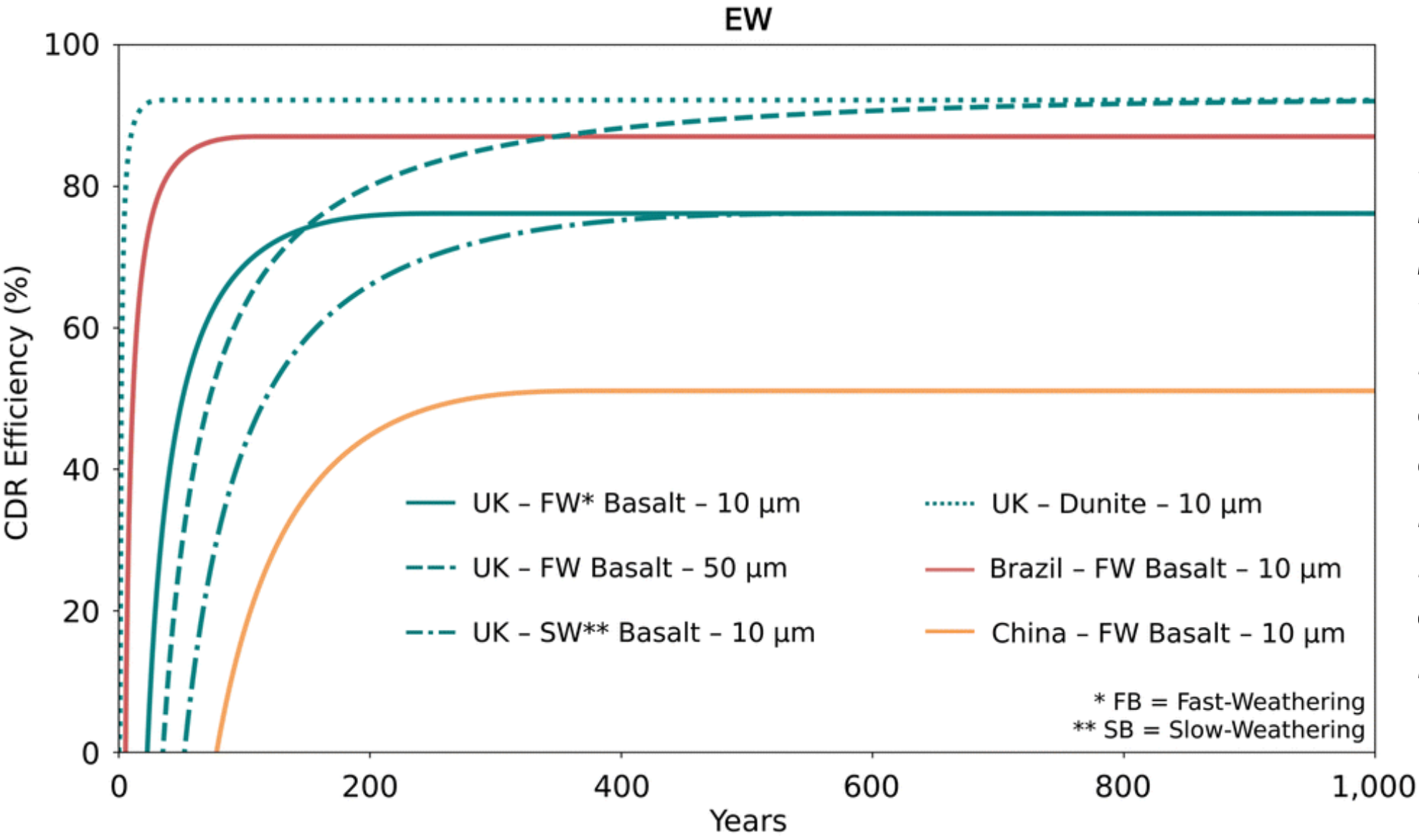
Enhanced Weathering



Source: Atmosphere via rock dissolution

Sink: Dispersed inorganic carbon in soils and waterways

System: Mining, grinding, transport, and spreading

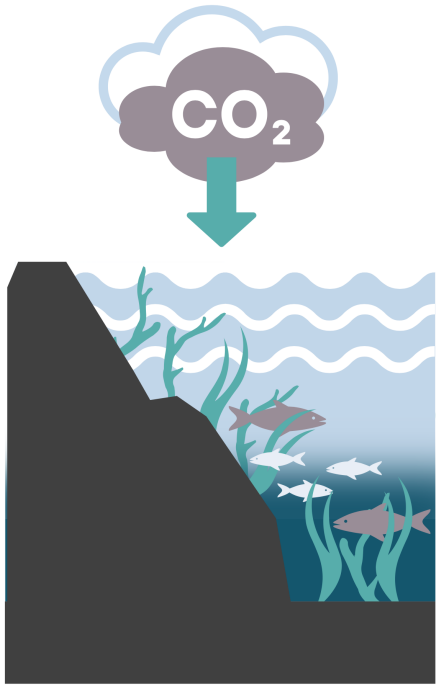


Enhanced weathering is a slow, difficult to monitor process *whose speed is greatly influenced by environmental conditions. Smaller rocks size is faster but increase energy use and could lead to health hazards.*

From: Chiquier et al 2022
DOI: 10.1039/D2EE01021F

Ocean CDR

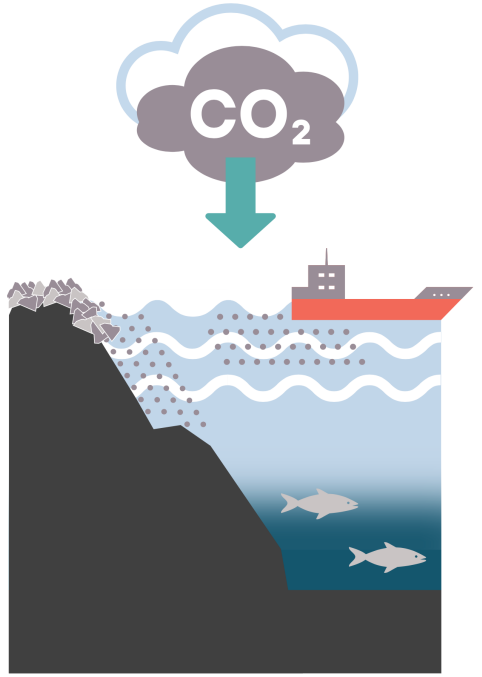
Typically designed to extract CO_2 from surface water to allow the ocean to absorb more CO_2 from the atmosphere



Ecosystem Restoration

Extraction by marine biomass

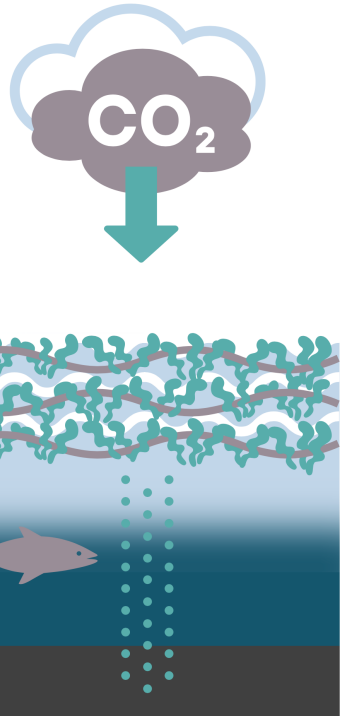
Storage in marine biomass



Ocean Alkalinity Enhancement

Extraction by dissolved minerals

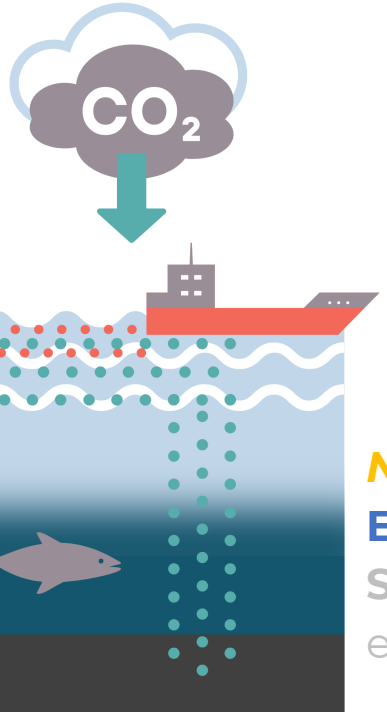
Storage in ocean water and sediment.



Seaweed farming

Extraction by macroalgae

Storage in deep ocean ecosystems and sediment.



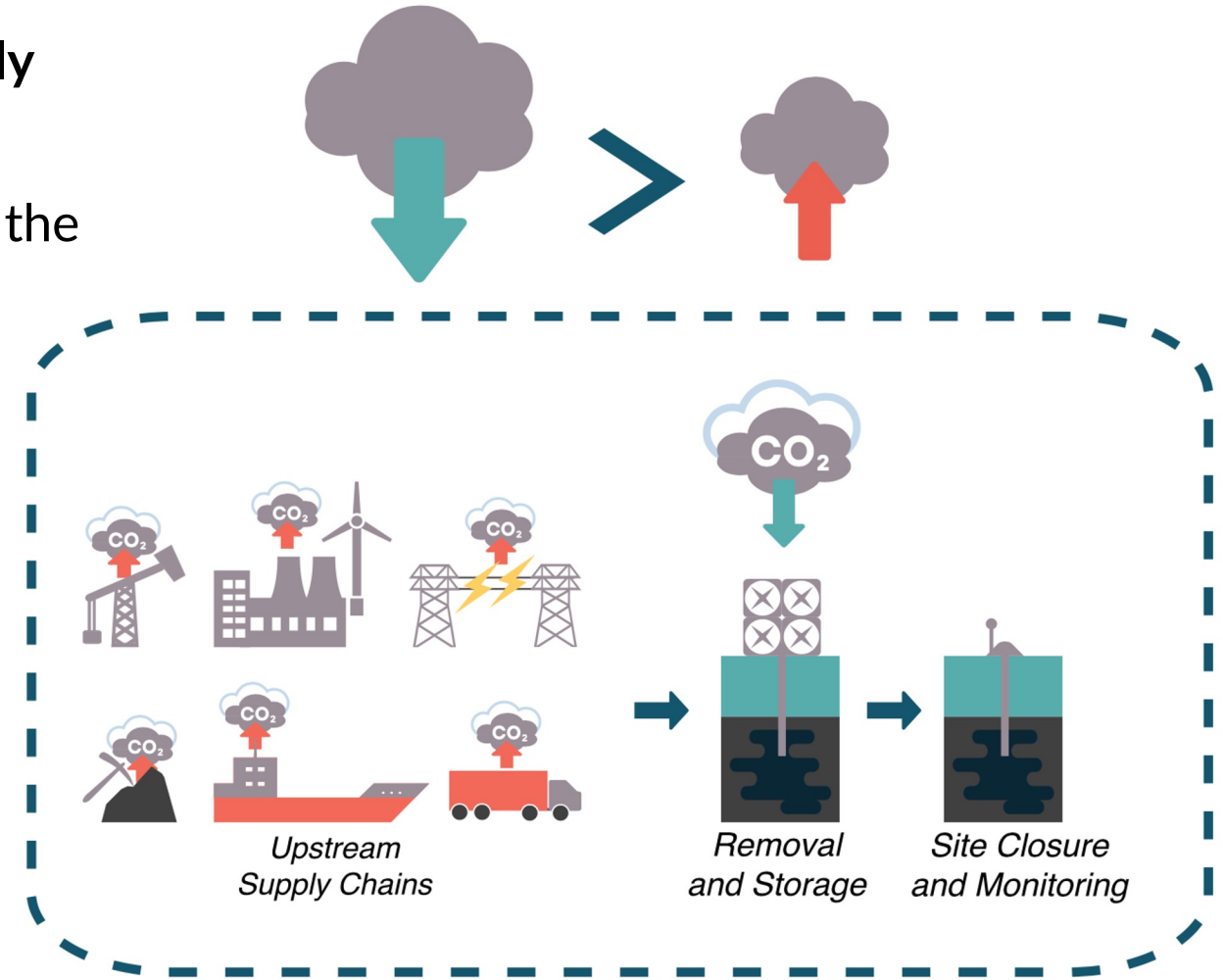
Nutrient fertilization

Extraction by phytoplankton

Storage in in deep ocean ecosystems and sediment.

All together now:

1. CO_2 is **physically extracted** from the atmosphere.
2. The extracted atmospheric CO_2 is **permanently stored**.
3. All greenhouse gas emissions associated with the removal and storage processes are comprehensively estimated and included.
4. More atmospheric CO_2 is permanently stored than greenhouse gases are emitted in the removal and storage processes and their complete supply chains.



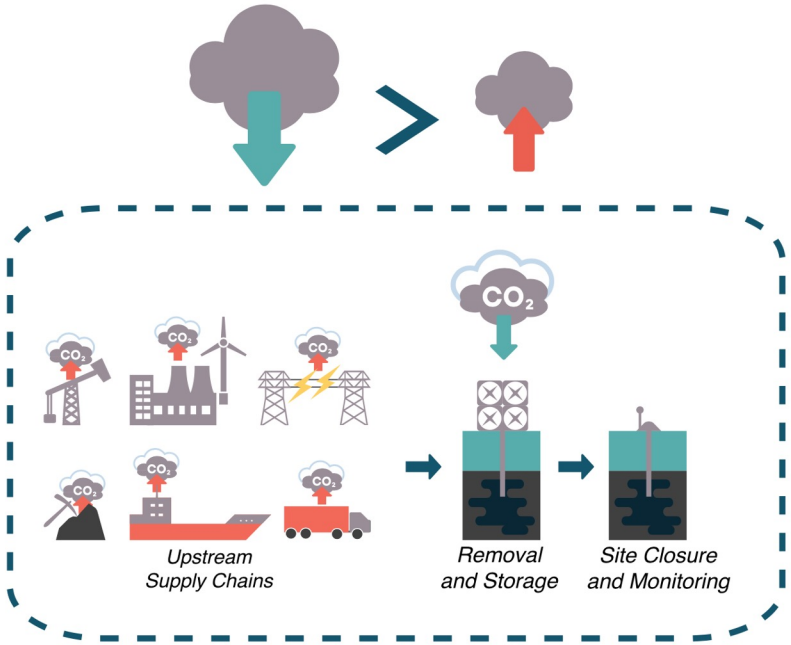
From: Tanzer et al (2019)
DOI: 10.1039/C8EE03338B

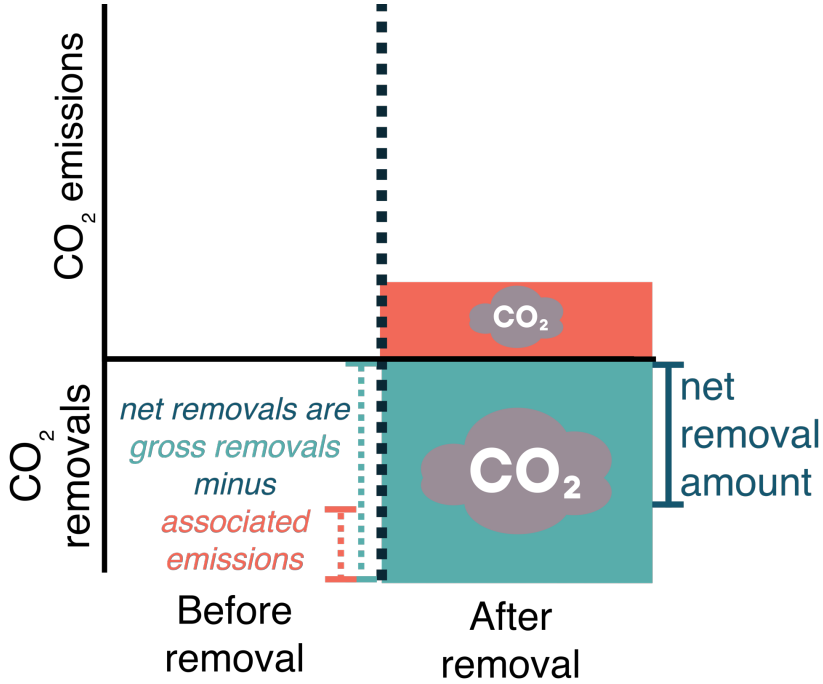
Accounting for CDR

Permanently stored atmospheric CO_2 – All associated GHG emissions = **Net CDR**

Only *net* CDR measures the decrease in atmospheric GHGs

Only *physical* flows of GHGs can be included in net CDR
(avoidance and reductions should always be counted separately)





What to Remember

- CDR are a resource- and energy- intensive form of atmosphere remediation
- CDR requires knowing the source, sink, and system — every implementation will be different
- All CDR systems still have a lot of uncertainties regarding large scale use
- The smaller the system, the easier monitoring and verification will be
- **CDR must be *in addition to* rapid and massive emission reduction**
- CDR is just one of many things we need to do a lot of to overcome the climate crisis
  - The less CDR we need, the more likely we'll have enough
- The more we research and invest in NETs now, the more likely we'll have it when we need it

Questions to ask about all CDR

- What is a given NET's **source**, **sink**, and **system**?
- What is the **net removal** — how much CO_2 has been permanently stored *minus* associated emissions from direct processes, supply chains, and indirect system changes?
- [How] can the **permanent storage** of carbon be **monitored** and **maintained**?
- **Is this NET a good use of resouces** with acceptable trade-offs?
- **Is there a better alternative (**i.e. reducing emissions) to using CDR?
- What is our plan if the CDR doesn't scale as anticipated?

Thank You

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