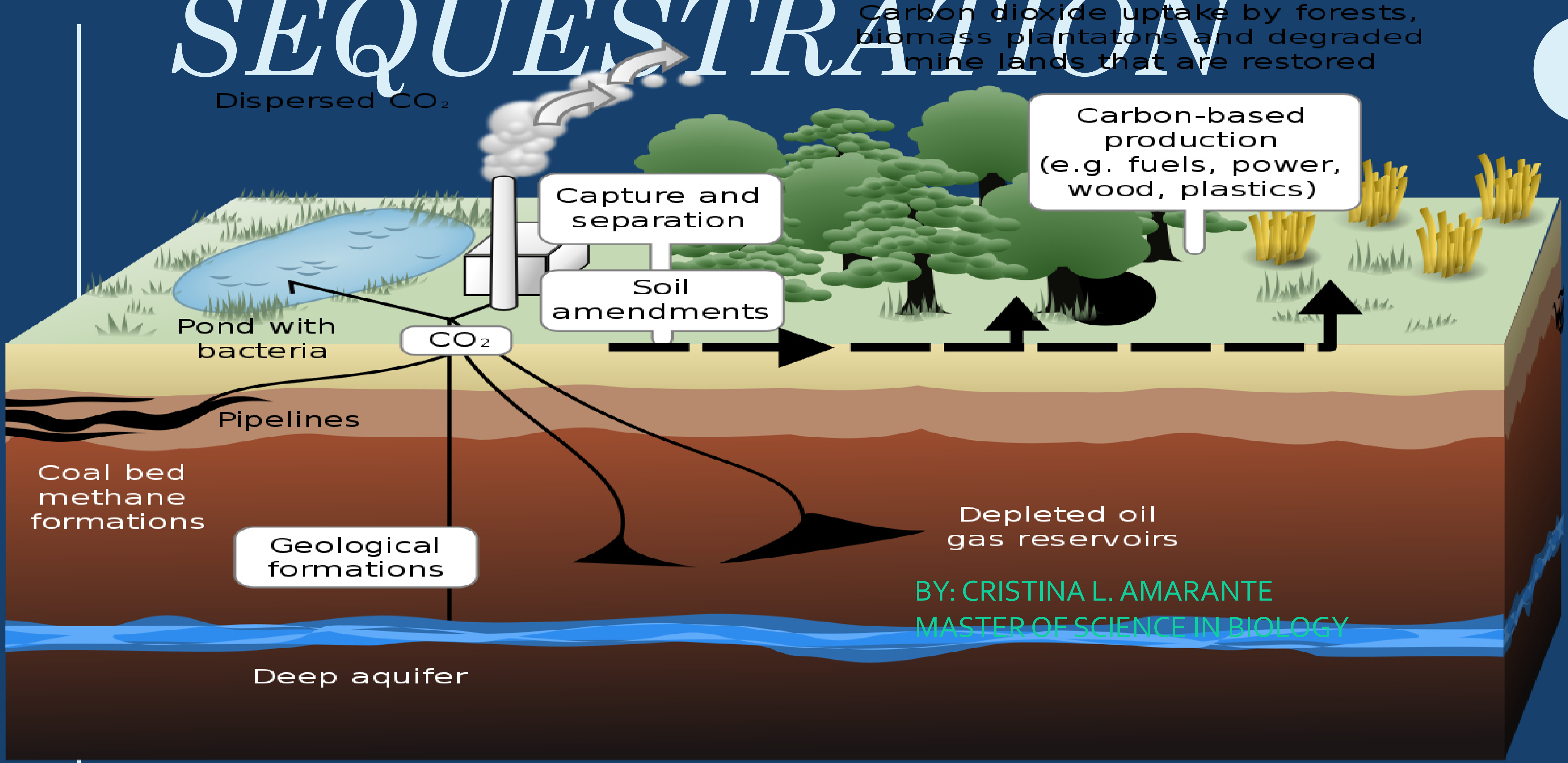
CARBON SEQUESTRATION



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CONTENT

- Introduction
- Objectives
- What is Carbon Sequestration
- Carbon Capture, Transport, Injection and Storage
- Scenarios
- Conclusion
- Case Studies (Local and International)
- References

DEFINITION OF TERMS:

- ***Carbon sequestration*** *describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change.*

- ***Carbon Cycle*** essentially nature's way of reusing carbon atoms in different ways and in varying places. It is the process in which carbon travels from the atmosphere into organisms and the Earth and into the atmosphere.

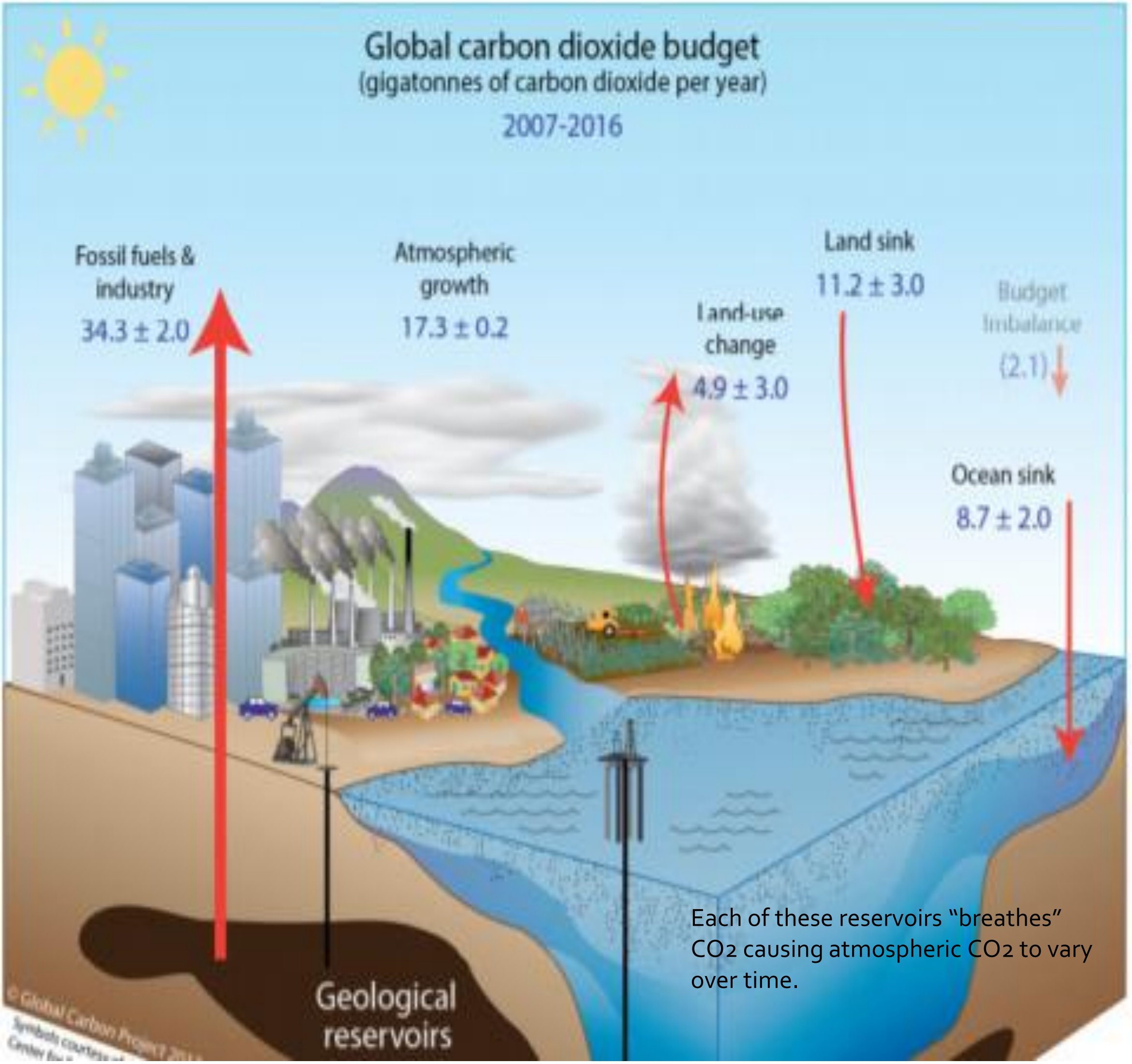
- ***Greenhouse gases*** that contributes to the greenhouse effect that include water vapor, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals.

- ***CO_2 Emission*** are global externality. Emissions anywhere affect everyone and because of the large volume of trade of fossil fuels.

Introduction

- The Earth's atmosphere contains carbon dioxide (CO_2) and other greenhouse gases (GHGs) that act as a protective layer, causing the planet to be warmer than it would otherwise be.
- This heat retention is critical to maintaining habitable temperatures. If there were significantly less CO_2 in the atmosphere, global temperatures would drop below levels to which ecosystems and human societies have adapted.
- As CO_2 levels rise, mean global temperatures are also expected to rise as increasing amounts of solar radiation are trapped inside the "greenhouse."
- The concentration of CO_2 in the atmosphere is determined by a continuous flow among the stores of carbon in the atmosphere, the ocean, the earth's biological systems, and its geological materials.
- PHILIPPINES – In 2018, CO_2 emissions per capita for Philippines was 1.39 metric tons. CO_2 emissions per capita of Philippines increased from 0.99 metric tons in 1999 to 1.39 metric tons in 2018 growing at an average annual rate of 1.92%.
- USA – The U.S. Energy Information Administration estimates increased 2.7% (139 million metric tons) in 2018. U.S. energy-related CO_2 emissions were 222 MMmt higher when compared with the average 2007–2017 trend.

Global Carbon Cycle



Each of these reservoirs “breathes” CO_2 causing atmospheric CO_2 to vary over time.

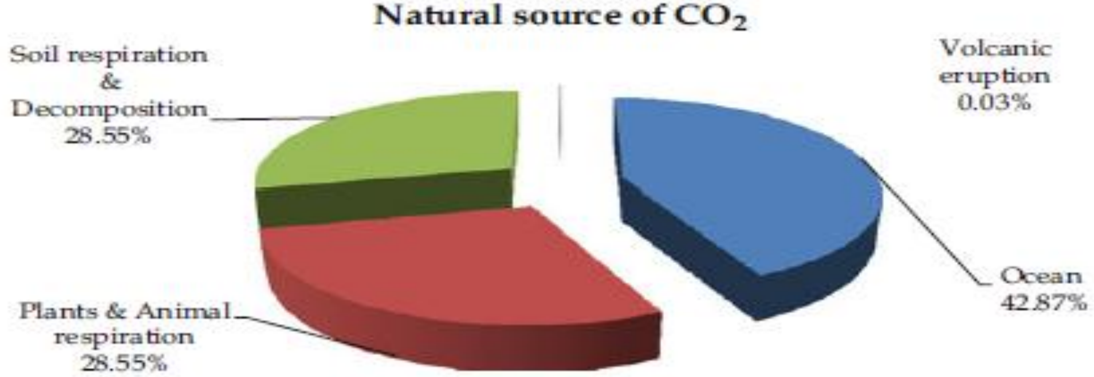
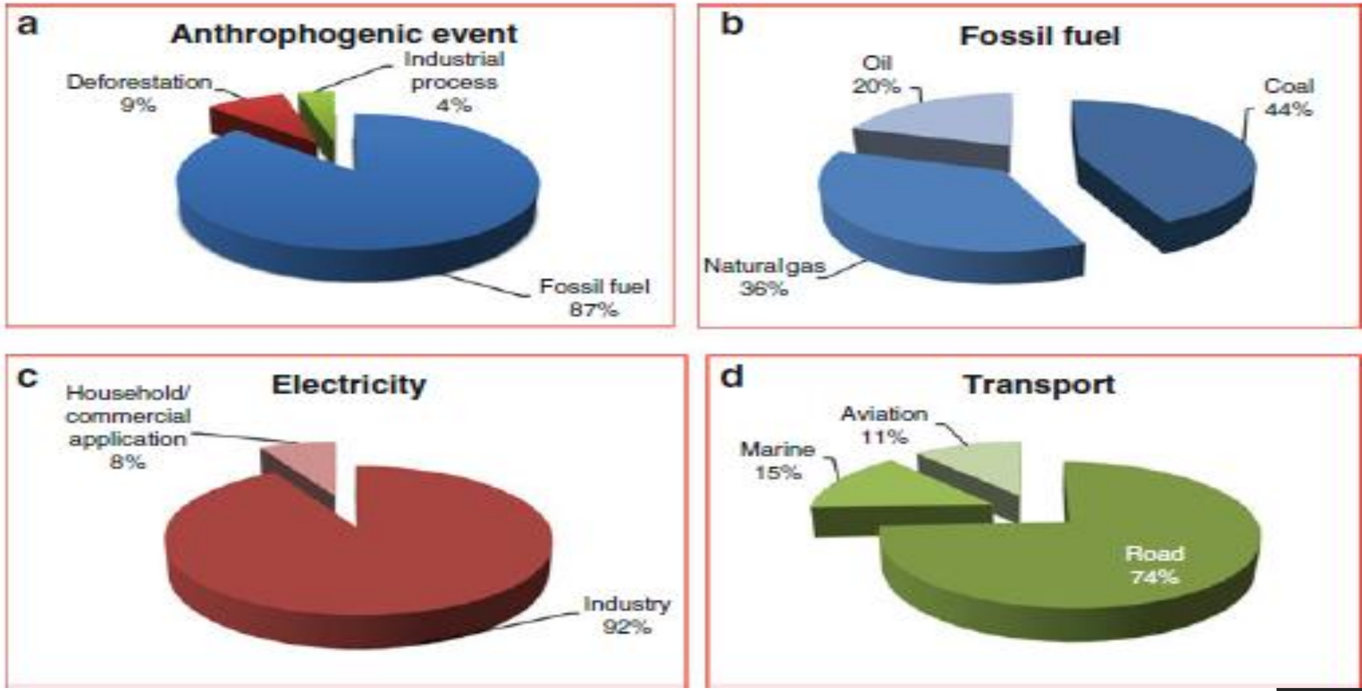
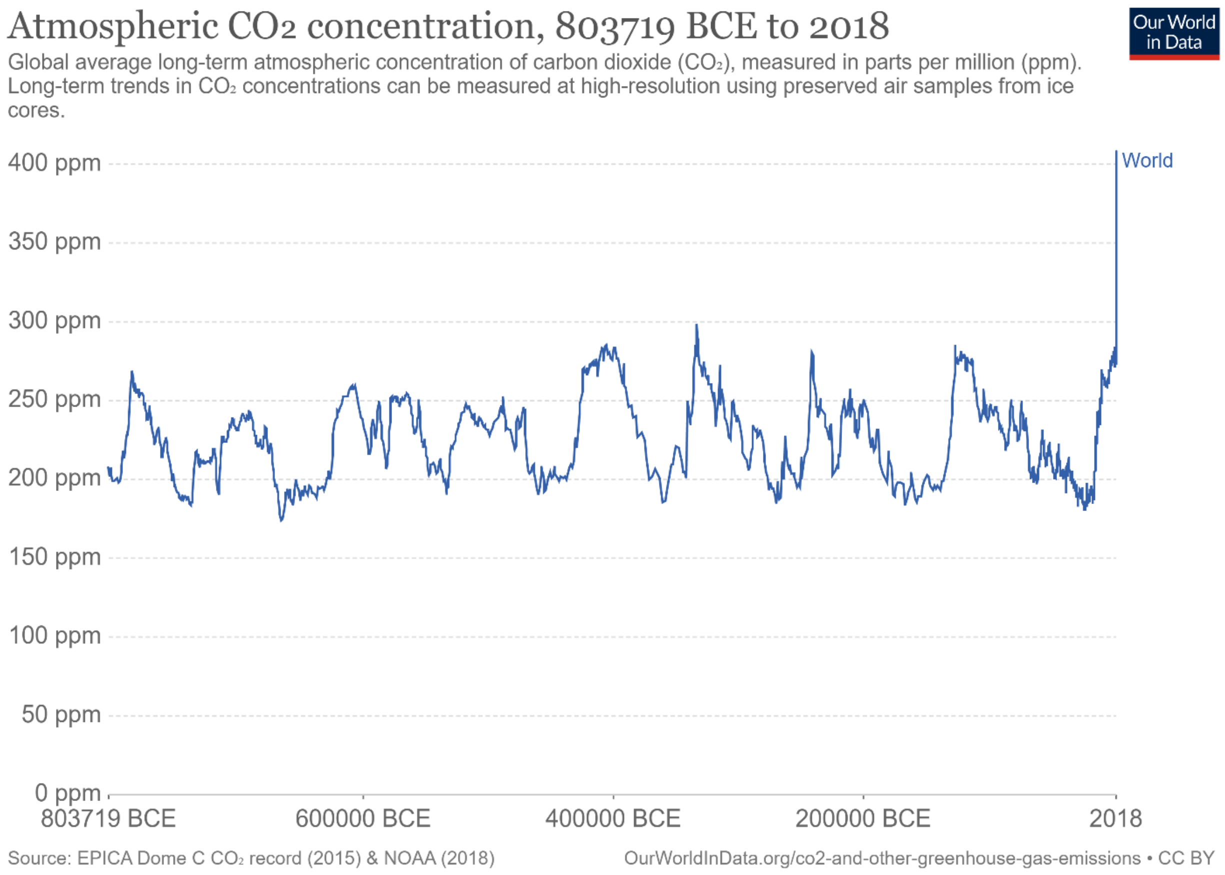


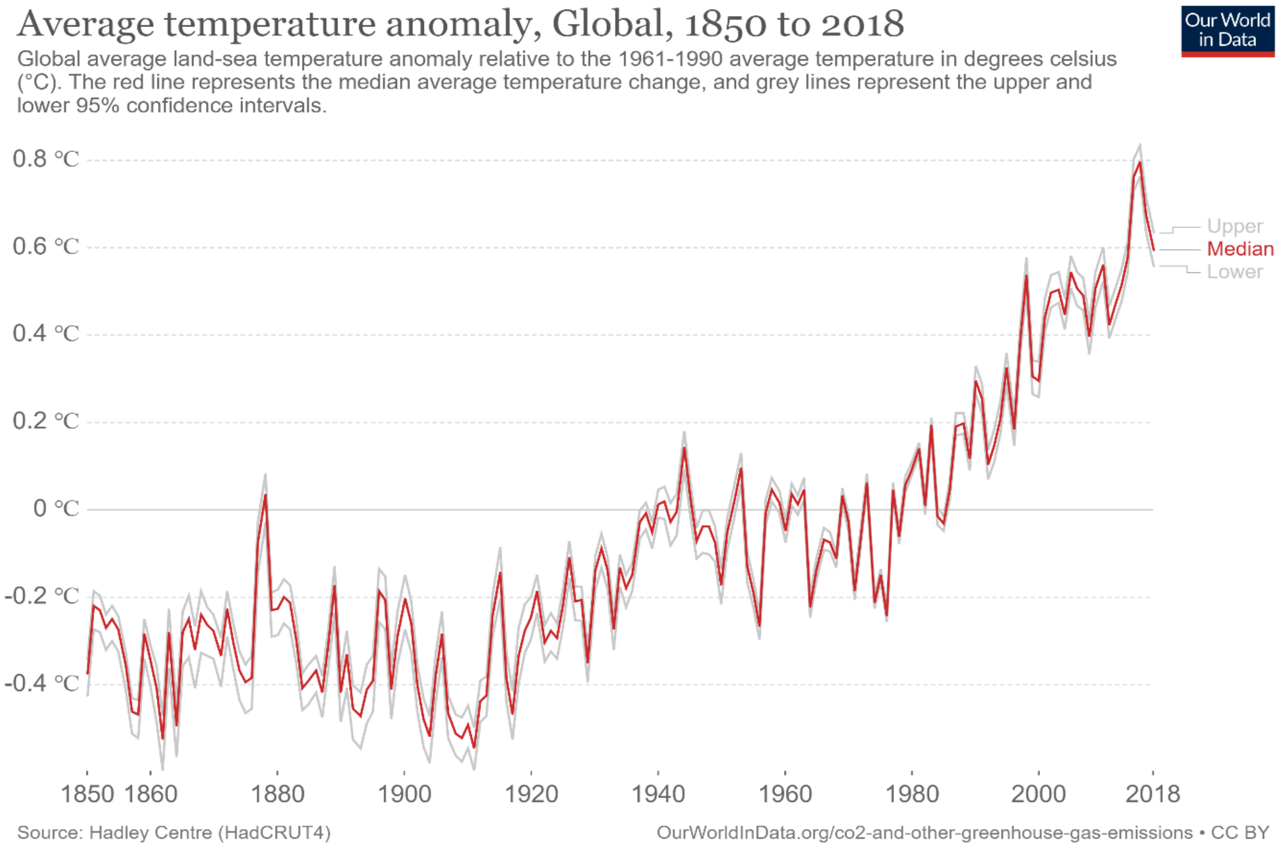
Fig. 1 Different sources of CO_2 by natural phenomena



- Understanding the global Carbon cycle and its perturbation by anthropogenic activities is important for developing viable strategies for mitigating climate change.

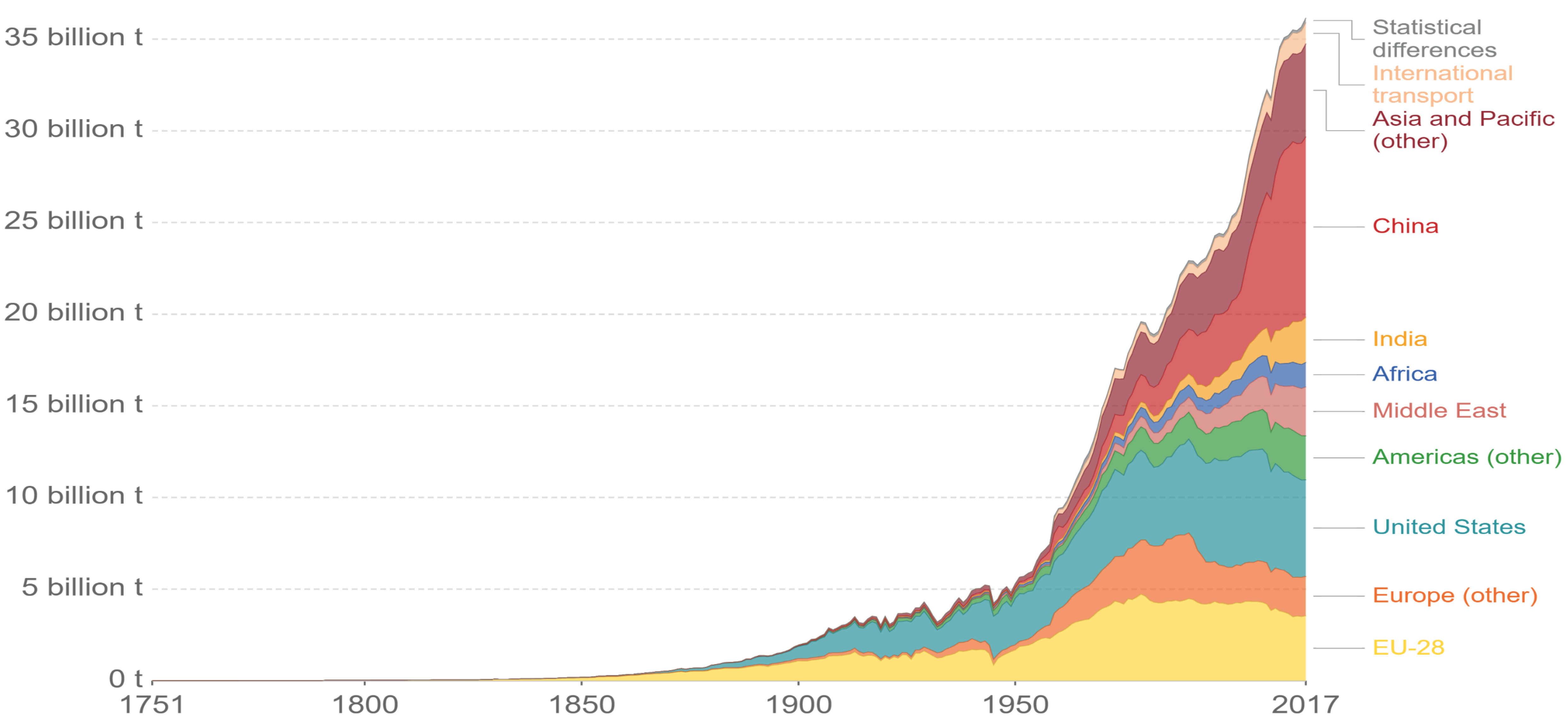


We see a rapid rise in **global CO2 concentrations** over the past few centuries, and in recent decades in particular. For the first time in over 800,000 years, concentrations did not only rise above 300ppm but are now well over 400ppm.



We see that over the last few decades, **global temperatures** have risen sharply — to approximately 0.7°C higher than our 1961-1990 baseline.

Annual total CO_2 emissions, by world region, 1751 to 2017



Source: Carbon Dioxide Information Analysis Center (CDIAC); Global Carbon Project (GCP)
Note: The difference between the global estimate and the sum of national totals is labeled “Statistical differences”.

Objectives

- To understand the Carbon Sequestration and the focus areas: ocean, terrestrial and geological sequestration.
- To determine the effectiveness of these sequestration (i.e., its impacting mitigating climate change), and understand the resulting changes in the biogeochemical cycles of the oceans.
- To reduce CO_2 emissions and discuss the process and technological option of CO_2.
- To indicate the best management practices to enhance carbon content and to maintain it at the maximum practical level for a given area.

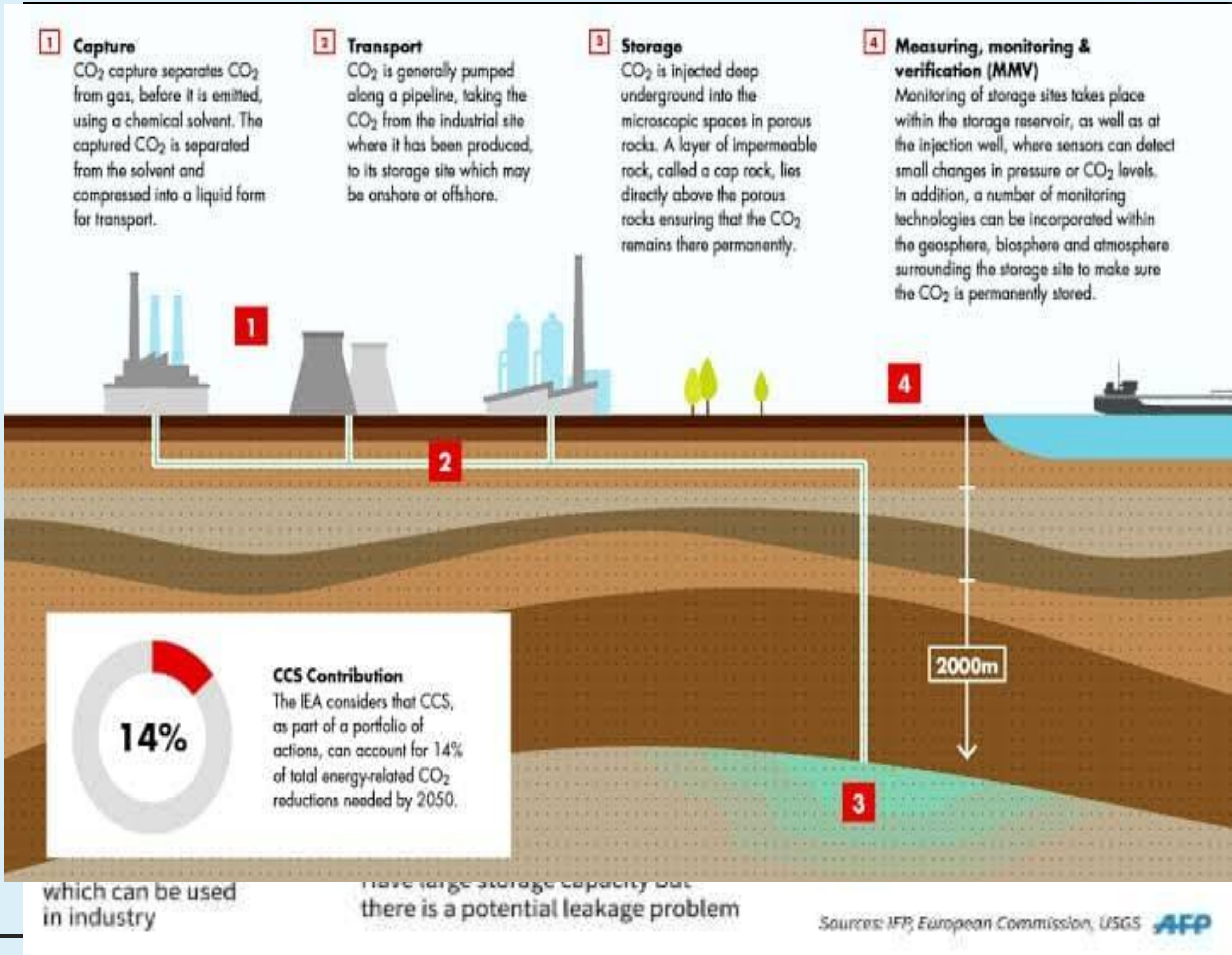
Carbon Sequestration

Basically four types:
-Oceanic
-Terrestrial
-Geological
-Mineral (Direct and indirect carbonation)

- Importantly, **carbon sequestration** is both a natural and artificial process by which carbon dioxide is removed from the Earth's atmosphere and then stored in liquid or solid form.
- **carbon sequestration** means capturing the carbon dioxide (CO_2) produced from new and old coal-powered power plants and large industrial sources before it is released in the atmosphere.
- Once captured, the CO_2 is put into long term storage either by storing it in carbon sinks (such as oceans, forests or soils) or underground injection and geologic sequestration into deep underground rock formations.
- Carbon dioxide (CO_2) capture and sequestration (CCS) is, therefore, a 3 step process that involves: capture, transport and storage.

CCS PROCESS

Capture
Transport
Injection
Storage



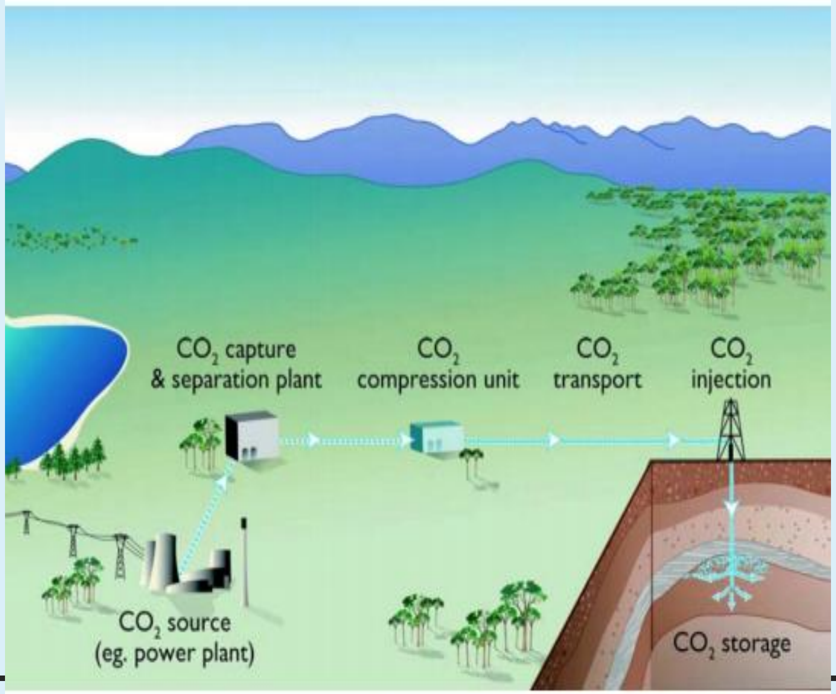
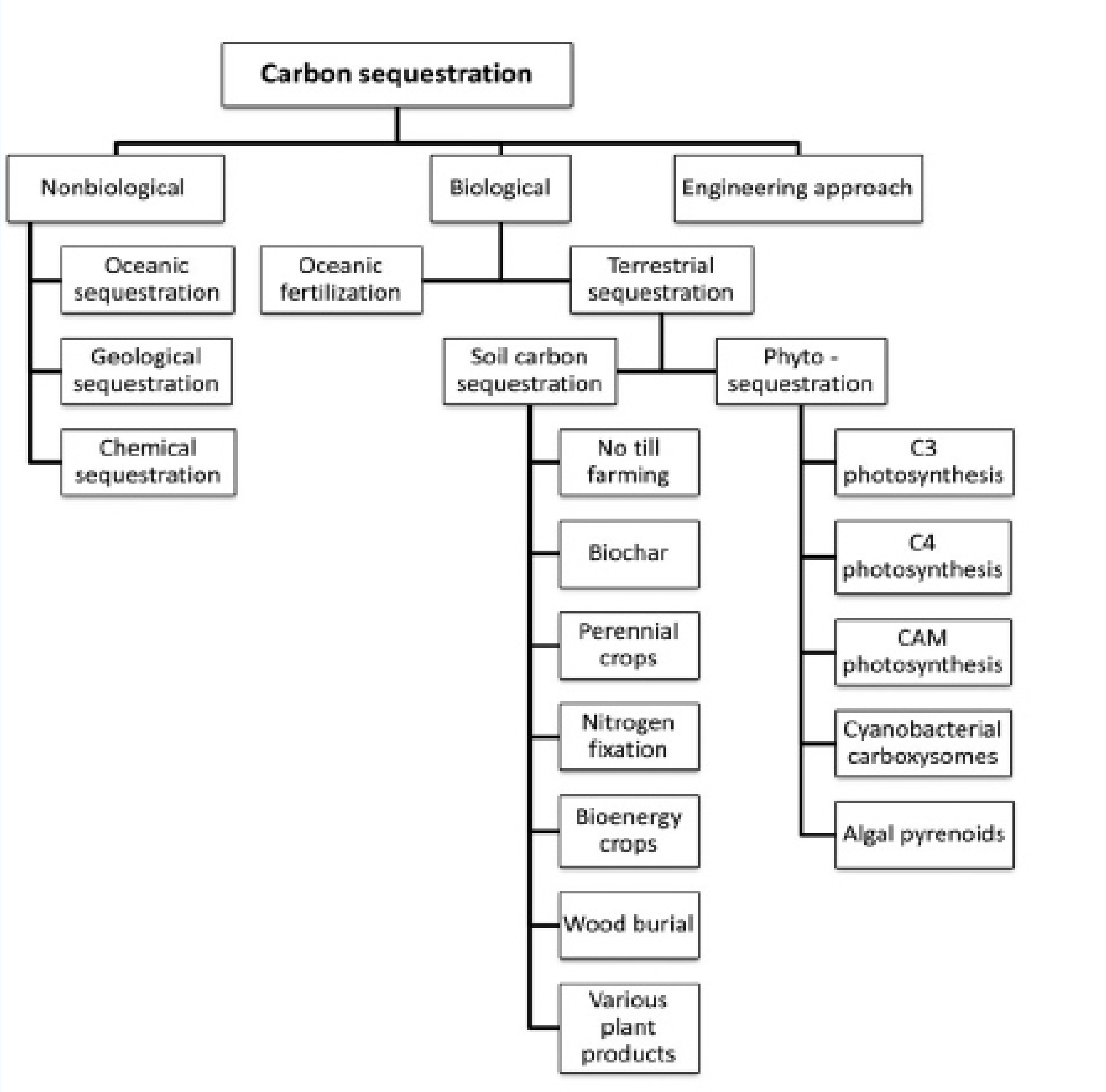


Figure 1. Schematic of the Carbon dioxide Capture and Storage (CCS) process (CO2CRC, http://www.co2crc.com.au/aboutccs/).

CCS is various methods for capturing, transport and permanently storing anthropogenic CO2.

METHODS

Basically four types:
Oceanic
Terrestrial
Mineral (Direct and indirect carbonation)
Geological



Ocean Sequestration

- The ocean is the largest sink of atmospheric CO_2 (about 7 petagrams (Pg) per year) (1 Pg = 1 gigaton = 10^{15} g).
- The CO2 absorbs in sea water it creates carbonic acid, which lowers the pH level of the water. This is called ocean acidification.
- Both ocean warming and acidification is causing coral bleaching. This, in essence, is killing coral reefs, which are one of the most diverse and ecologically important habitats in the world.

- Ocean carbon sequestration (OCS) is a method to distribute CO_2 more evenly throughout ocean depth and minimize surface ocean impacts. There are two major methods of OCS – direct injection and ocean fertilization (promoting photosynthetic fixation of CO_2 by ocean organisms).

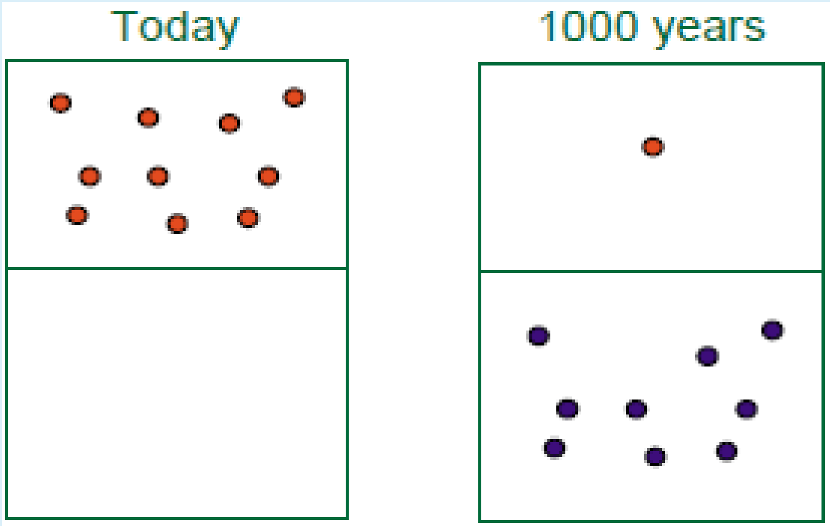
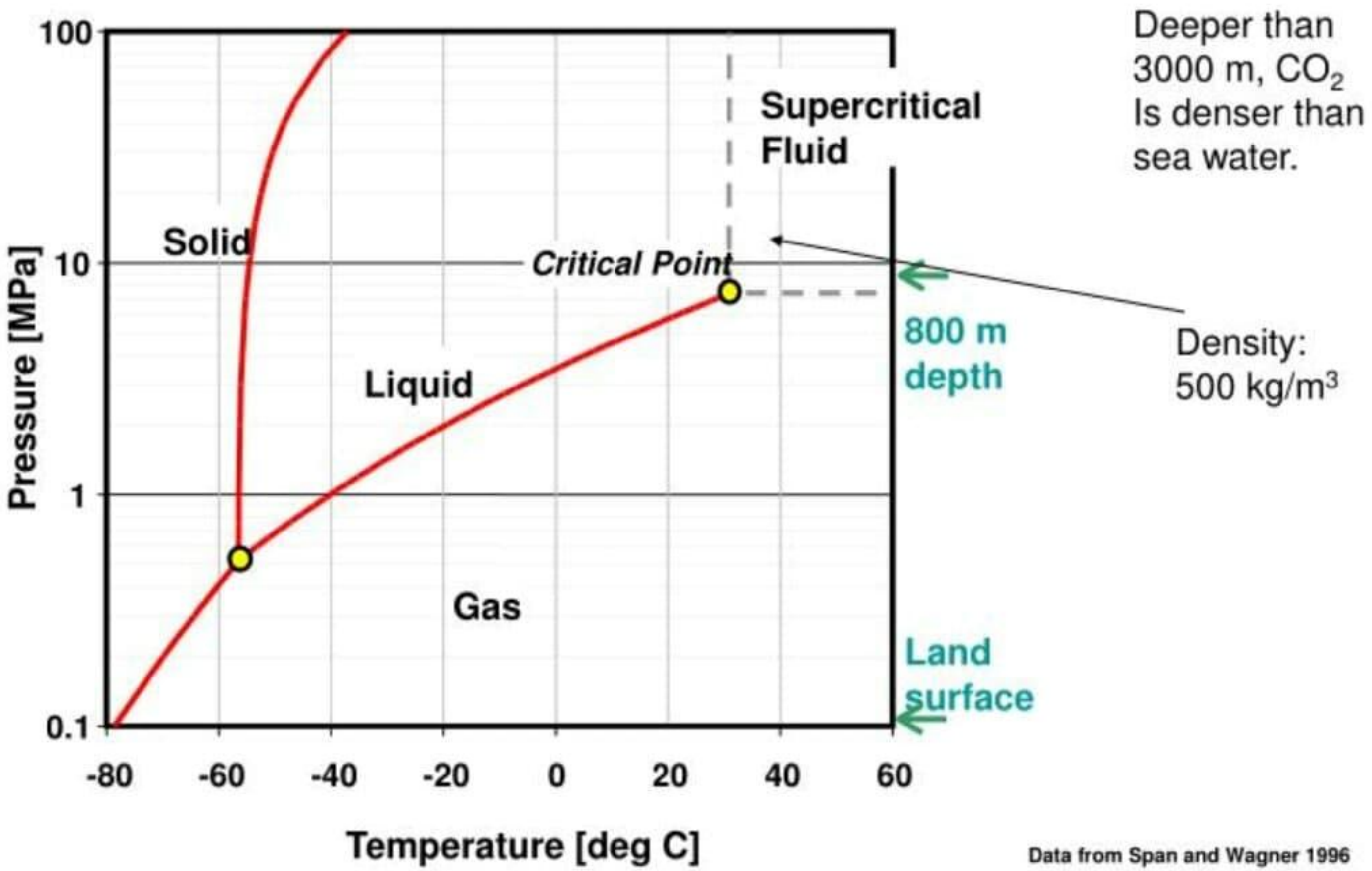


Fig. 3.1. Every year the ocean actively takes up one-third of our anthropogenic CO_2 emissions. Eventually (over 1000 years), about 85% of today's anthropogenic emissions of CO_2 will be transferred to the ocean. Ocean sequestration strategies attempt to speed up this ongoing process to reduce both peak atmospheric CO_2 concentrations and their rate of increase.

CO_2 phase diagram



OCEAN DIRECT INJECTION

Five methods:

1. Dry ice released at the ocean surface from a ship.
2. Liquid CO_2 injected at a depth of about 1000 m from a pipe towed by a moving ship and forming a rising droplet plume.
3. Liquid CO_2 injected at a depth of about 1000 m from a manifold lying on the ocean bottom and forming a rising droplet plume.
4. A dense CO_2 seawater mixture created at a depth of between 500 to 1000 m forming a sinking bottom gravity current.
5. Liquid CO_2 introduced to sea floor depression forming a stable " deep lake" at a depth of about 4000 m.

- Separation cost driver; effective in reducing atmospheric CO_2 for hundred of years.

OCEAN IRON FERTILIZATION (OIF)

- Fertilization of the oceans with micronutrients (such as iron) and macronutrients (such as nitrogen and phosphorus) is a strategy that is being considered to enhance drawdown of CO_2 from the atmosphere and thus accelerate the biological pump.
- Because certain areas of the ocean have low levels of phytoplankton yet a high concentration of nitrogen and phosphorus, it was realized that a lack of iron might limit phytoplankton growth (see the IRONEX sidebar) (Chisholm 1992).
- The potential risk of fertilization leading to **eutrophication** must be determined. Eutrophication causes oxygen depletion, which could kill species that require oxygen; in some cases, it can lead to the production of methane by microorganisms.
- Relatively inexpensive; maximum long te flux may be < 1 PgC/ yr

Ocean Sequestration

The CO_2 emissions are relatively pure from coal-fired power plants and could be isolated and injected into the ocean. After CO_2 capture, the CO_2 would be transported to the ocean via a pipe or ship to the ocean for direct injection. Technologies for CO_2 direct injection include: Liquid CO_2 droplets, CO_2 laden seawater , Solid CO_2 (dry ice), and CO_2 lake formation .

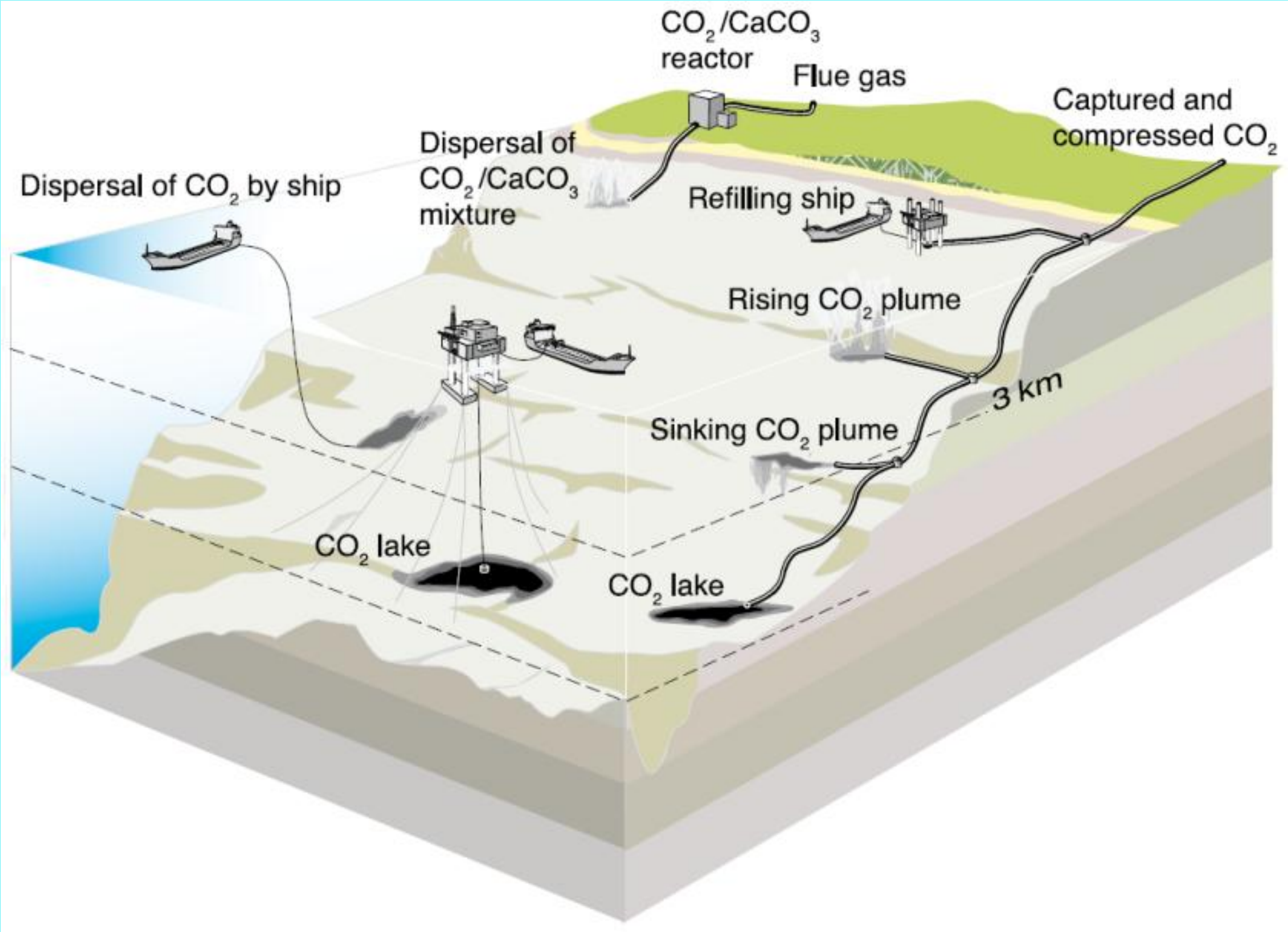
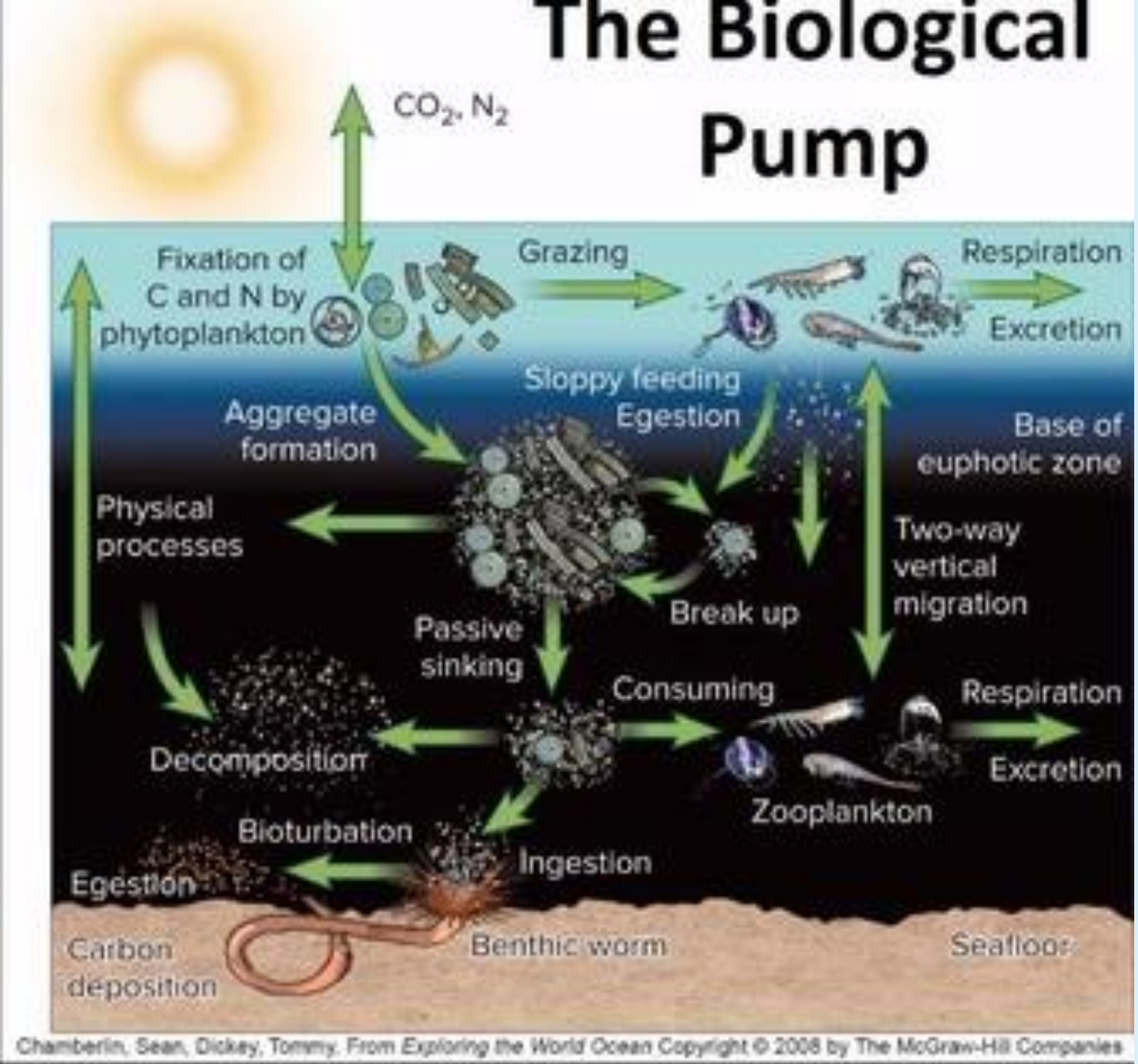


Fig. 3.3. For injection of CO_2 at depths of 1000 to 2000 m, it has been suggested that liquid CO_2 be transported from shore through a pipeline for discharge from a manifold lying on the ocean bottom. Another proposal is to transport the liquid CO_2 by tanker and then discharge it from a pipe towed by the moving ship.



Although the ocean's biomassrepresents about 0.05% of the terrestrial ecosystem, it converts about as much inorganic carbon to organic matter (about 50 GtC/year) as do processes on land. The photosynthetic fixation of CO2 by ocean organisms, followed by the sinking and slow remineralization (conversion to CO2) of organic carbon, is a natural process for sequestering CO2 in the deep sea. This process is often referred to as the "biological pump".

Terrestrial Sequestration (Soil & Vegetation)

- **Terrestrial (or biologic) sequestration** means using plants to capture CO_2 from the atmosphere and then storing it as carbon in the stems and roots of the plants as well as in the soil. In photosynthesis, plants take in CO_2 and give off the oxygen (O_2) to the atmosphere as a waste gas.

- Soils are critical to plant production, but they also are essential for carbon sequestration (soils currently contain ~75% of the terrestrial carbon).

- **Land-use management and agricultural practices** have great potential to sequester carbon by protecting soils. About one-third of the current 1.5 billion tonnes of carbon emitted to the atmosphere because of changes in tropical land use is from oxidation of soil carbon.

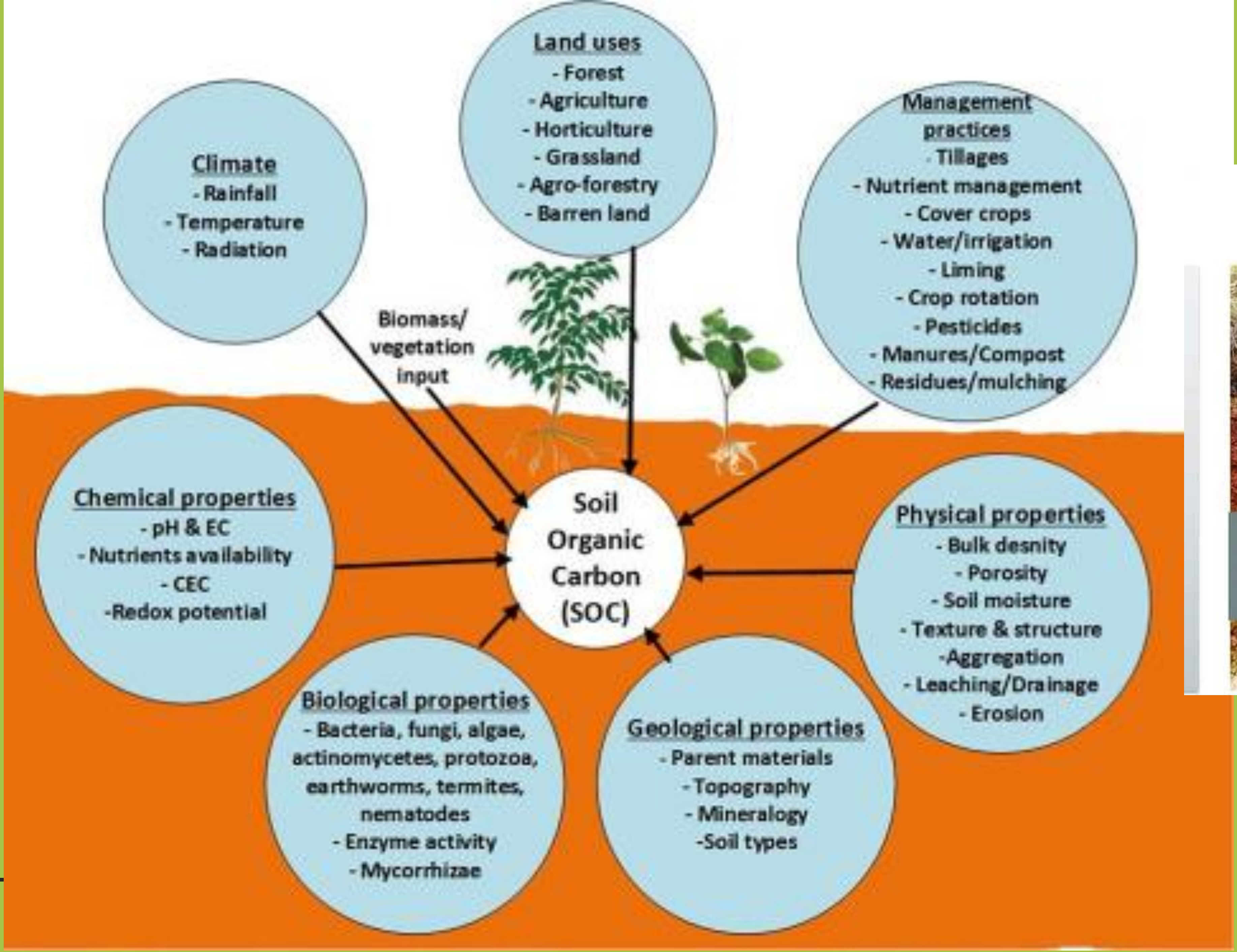
- The total amount of carbon "stored" in terrestrial ecosystems is large (~2000 ± 500 GtC).

BENEFITS OF SOIL CARBON SEQUESTRATION:

- improved soil and water quality
- decreased nutrient loss
- reduced soil erosion
- better wildlife habitats
- increased water conservation, and more biomass products
- Restoring wetlands to sequester larger quantities of carbon in sediment will also preserve wildlife and protect estuaries.
- Improved agricultural performance

MANAGEMENT PRACTICES TO SEQUESTER CARBON AND ENCOUNTER LAND DEGRADATION:

- afforestation of marginal crop and pasture land
- tillage management, crop rotation, residue management
- forest management (reducing deforestation, improving stocking control, implementing fire management)
- management for pest and disease control and control of invasive species
- decrease urbanization and land conversion of forests to agricultural use
- Tree Plantings
- Animal manure application
- Green- manure cropping systems
- Improved grassland management
- Cropland – grazingland rotations
- engineer new plants that have improved water efficiency, nutrient utilization, salt tolerance, and p tolerance


Land uses
- Forest
- Agriculture
- Horticulture
- Grassland
- Agro-forestry
- Barren land
Climate
- Rainfall
- Temperature
- Radiation
Management practices
- Tillages
- Nutrient management
- Cover crops
- Water/irrigation
- Liming
- Crop rotation
- Pesticides
- Manures/Compost
- Residues/mulching
Biomass/ vegetation input
Soil Organic Carbon (SOC)
Chemical properties
- pH & EC
- Nutrients availability
- CEC
-Redox potential
Physical properties
- Bulk desnity
- Porosity
- Soil moisture
- Texture & structure
-Aggregation
- Leaching/Drainage
- Erosion
Biological properties
- Bacteria, fungi, algae, actinomycetes, protozoa, earthworms, termites, nematodes
- Enzyme activity
- Mycorrhizae
Geological properties
- Parent materials
- Topography
- Mineralogy
-Soil types

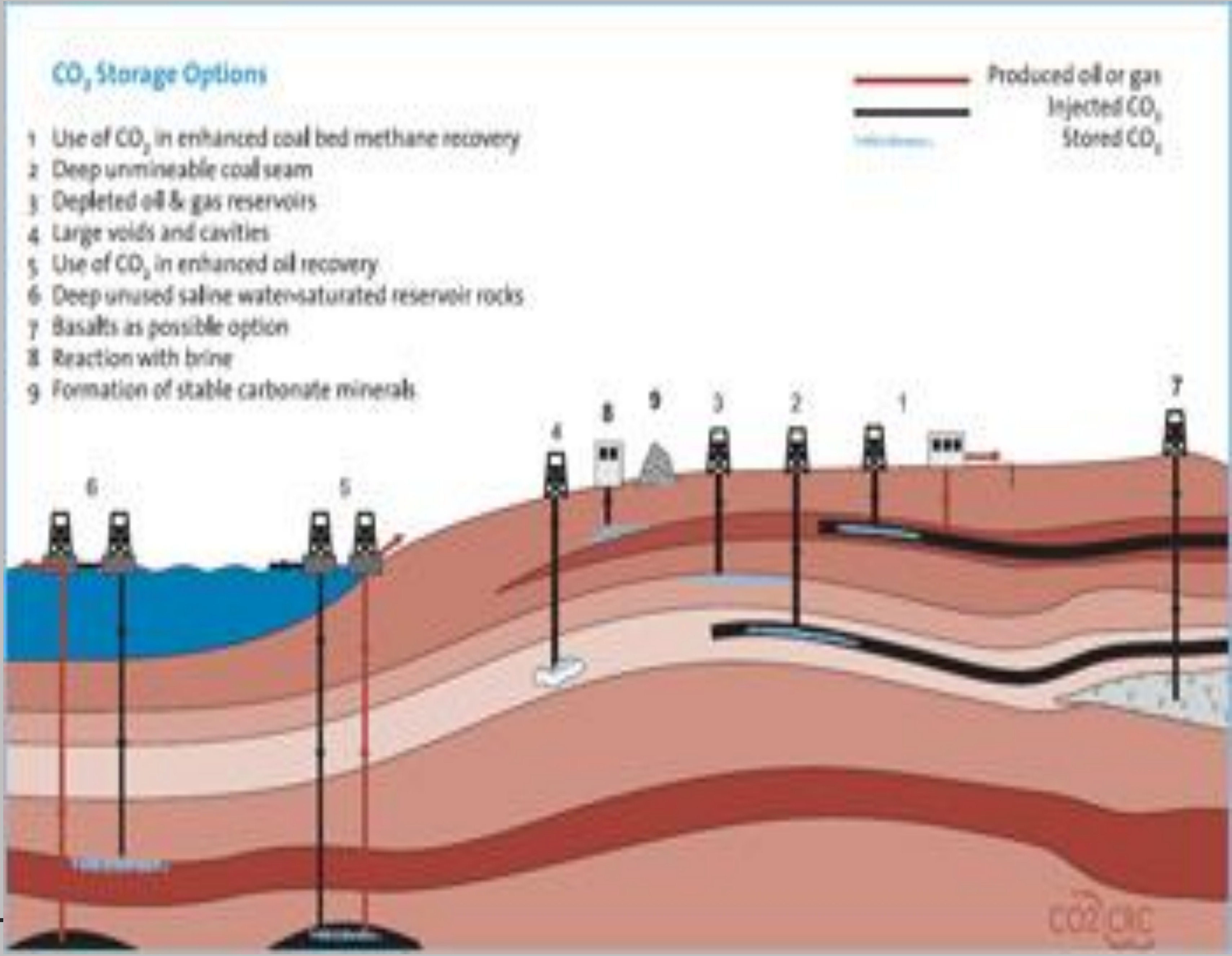

2400
giga
tonne C
Organic carbon stored in the soil globally (up to 2 m)

8.9 / 240

Geological Sequestration

Geologic carbon sequestration (GCS) = Geologic CO_2 storage

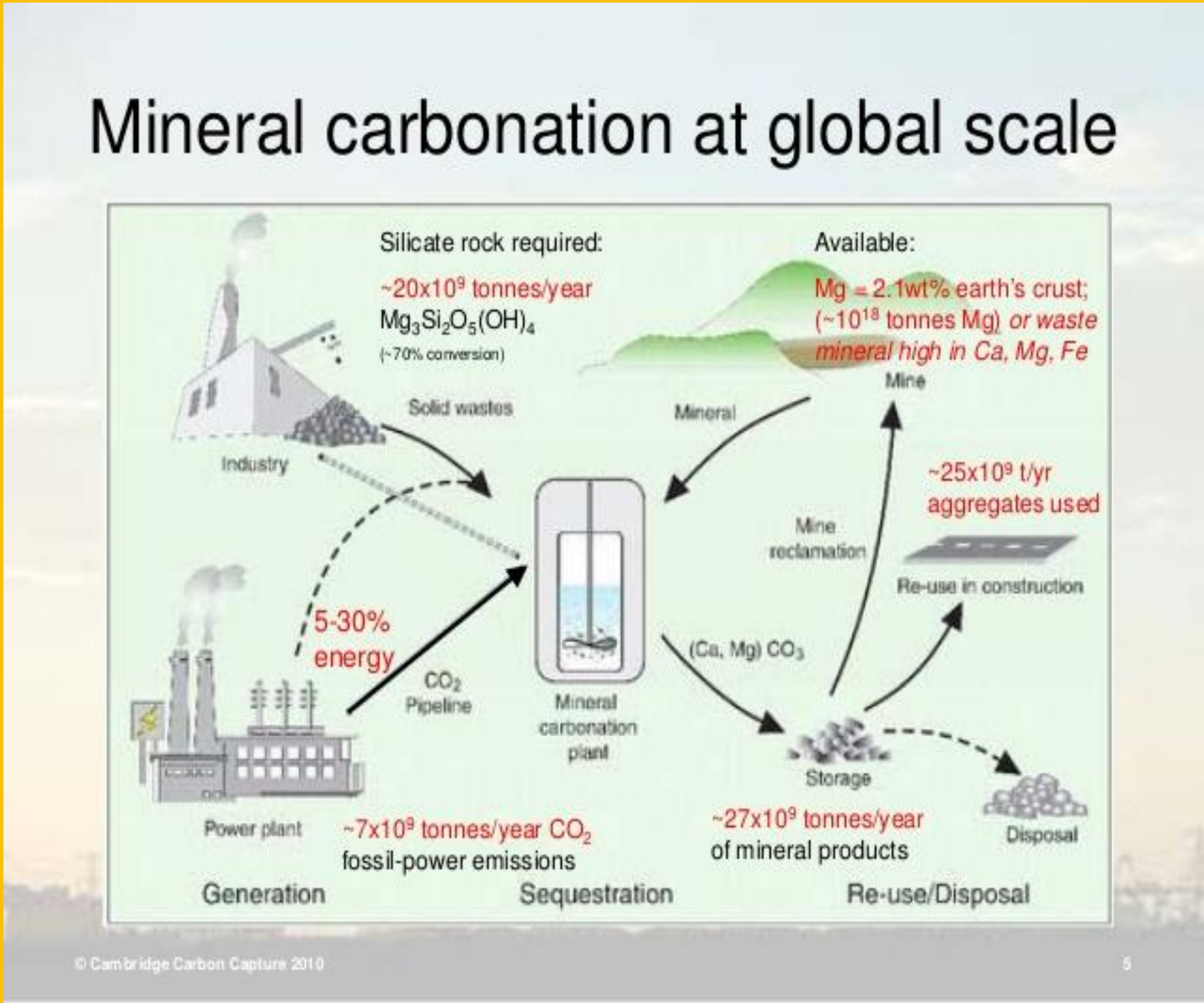
(GCS) - The last step of CCS in which CO_2 is injected through wells into deep subsurface formations for permanent storage.



Mineral Sequestration

1. **Direct carbonation** - accomplished through the reaction of a solid alkaline mineral with CO2 either in the gaseous or aqueous phase •

2. **Indirect carbonation** - involves the extraction of reactive components (Mg2+,Ca2+) from the minerals, using acids or other solvents, followed by the reaction of the extracted components with CO2 in either the gaseous or aqueous phase.



SCENARIOS:

- In Philippines, Dr. Chelo Pascua,the youngest Balik Scientist to visit the Mariano Marcos State University, his presentation focused on the concept of carbon dioxide capture and storage (CCS). Pascua cited opportunities for CCS in the Philippines as the country needs to feed a growing energy-hungry population and industry.
- MARICULT, a European consortium of government and industry, is currently exploring the commercial feasibility of fertilizing coastal waters to increase the fish harvest.
- The Chicago Climate Exchange(CCX) has developed two protocols defining general provisions, rules for estimating carbon in long-lived wood products, and guidelines for verification under the following two eligibility scenarios:
- 1. The protocol for crediting carbon in long-lived wood products for commercial forest product companies registered in CCX.
- 2. The protocol for crediting carbon in long-lived wood products for CCX forest offset providers/ aggregators.
- The Alberta trunk line project aims to transport captured carbon dioxide from the province's industrial heartland to boost oil recovery at declining oil fields in central Alberta.
- The Emirates Steel Factory in Abu Dhabi will capture 0.8 million tonnes a year from 2016 and use it for enhanced oil recovery. The carbon dioxide is a product of the steel production process and is currently emitted to the atmosphere.
- This will be another gas processing plant, stripping out carbon dioxide from natural gas at Barrow island off the coast of Western Australia. It will capture 3.4-4 million tonnes starting from 2016. The captured carbon dioxide will be stored in a saline aquifer.

Conclusion

- Greenhouse gas concentration in the atmosphere are increasing and the threat of the global climate change needs our attention.
- The carbon sequestration methods are effective tools sequester atmosphere CO_2 with a better practical application and other approaches.
- The ocean plays an important role in sustaining the biosphere, so any change in ocean ecosystem function must be viewed with extreme caution.
- A diversity of agricultural management practices can be employed to sequester more carbon in plants and soil.

Case Study: Philippines

Community Structure and Carbon Sequestration potential of Mangroves in Maasim, Sarangani Province, Philippines

by Ronald T. Bigsang Noreen Agonia, Christine Grace Toreta, Carl Joy Nacin, Christine Obemio & Tres

INTRODUCTION:	• The capacity of mangrove forests to act both as a source and sink of carbon makes them key ecosystems on the mitigation strategies against climate change.
METHODS:	• They evaluated the community structure and carbon sequestration potential of mangroves in Maasim, Sarangani Province using distribution and diversity indices and allometric equations. • Each belt transect was divided into six 10 x 10 m plots.
RESULTS:	• Five species were identified, namely: *Sonneratia alba*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia marina*, and *Bruguiera gymnorrhiza*. *R. mucronata* was the most dense (RD = 76.88%) and most frequent (RF = 44.53%) species in the area, but *S. alba* dominated (RO = 91.36%) in terms of basal area and was also the most important species (IV = 49.08%). • The forest has low to moderate diversity (H' = 0.715) and evenness (E = 0.444) with only two equally abundant species (ENS = 2.044). In terms of aboveground carbon density, *S. alba* was significantly greater in amount (446.275 Mg C ha-1) compared to the other species. Zone-wise, seaward stored most of the carbon mass amounting to 241.527 Mg C ha-1. • The total aboveground carbon stock in the mangrove forest was 15.130 Gg, which is equivalent to 55.526 Gt of CO2.
CONCLUSION:	• *S. alba* showed high potential of sequestering atmospheric carbon among the mangrove species identified. Meanwhile, the high forest aboveground carbon density implies high carbon sequestration activity. However, this could also mean huge amounts of carbon to be released back to the atmosphere if the forest is disturbed by human activities.

Case Study: USA

Soil Carbon Sequestration Accelerated by Restoration of Grassland Biodiversity by Yi Yang, David Tilman , George Furey & Clarence Lehman

INTRODUCTION:	• **Abandoned agricultural lands have been a particular area of interest for carbon capture and storage because of their high potential capacity for C sequestration. An estimated 430 million hectares of land globally has been cleared, cropped, degraded and then abandoned.** • **When agriculturally degraded lands are abandoned and undergo ecological succession, they remove atmospheric CO2 and sequester its C as soil organic matter.**
METHODS:	• Abandoned agricultural field at Cedar Creek Ecosystem Science Reserve, Minnesota USA. • 168 plots were established, each 13x13 m. • Planted with 16 perennial grassland/ savanna species (C4 grass species, C3 grass species, legume species and no legume herbaceous forb species. • oil C samples from the upper 0–20 cm soil depth and 2.5 cm in diameter, were collected,, 5 times 1994 before planting, 2000, 2004, 2006, and 2015. • The samples for each plot were first sieved to remove roots; the nine samples per plot were then combined, by depth, mixed, dried, mixed again, and then subsampled for grinding and archiving. Before analysis for total C, they were dried again for 5 days in glass vials, and analysed for total C by combustion and gas chromatography.
RESULTS:	• These results show that, during the second period (13–22 years) of experiment, the active restoration of high-diversity late successional plant communities caused soil C accrual to accelerate, with C pools accumulating at a rate 2–3 times that observed in natural succession site.
CONCLUSION:	• The restoration of high plant diversity may greatly increase carbon capture and storage rates on degraded and abandoned agricultural lands.

RESULTS

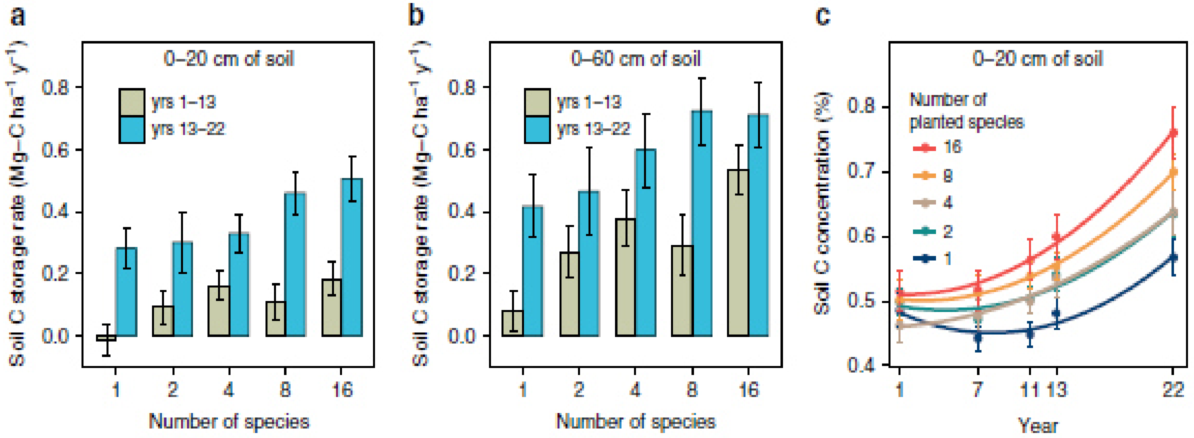


Fig. 1 Change in soil C over 22 years. **a**, **b** Average annual soil C storage rates over years 1–13 (green bars) and years 13–22 (blue bars) in upper 20 cm of soil (**a**) and in upper 60 cm (**b**) (Supplementary Table 1). Bars are means with standard errors. **c** Dynamics of soil C concentration in upper 20 cm of soil for plots planted with 1, 2, 4, 8, or 16 perennial grassland species (Supplementary Table 2). Dots are means with standard errors; fitted curves are quadratic

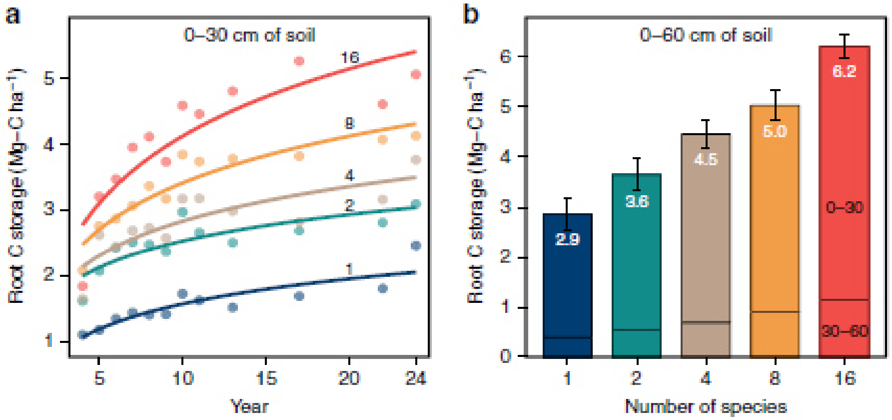


Fig. 2 Change in root C over 24 years. **a** Change in root C in upper 30 cm of soil under different experimentally imposed levels of plant species diversity. Dots indicate mean root C at a given year; curves fitted with log functions; the number on each curve indicates plant species diversity. **b** Total root C storage after 24 years of growth in upper 60 cm of soil. Numbers in white indicate mean total root C storage, error bars indicate standard errors, and numbers in black indicate soil depth increments (cm)

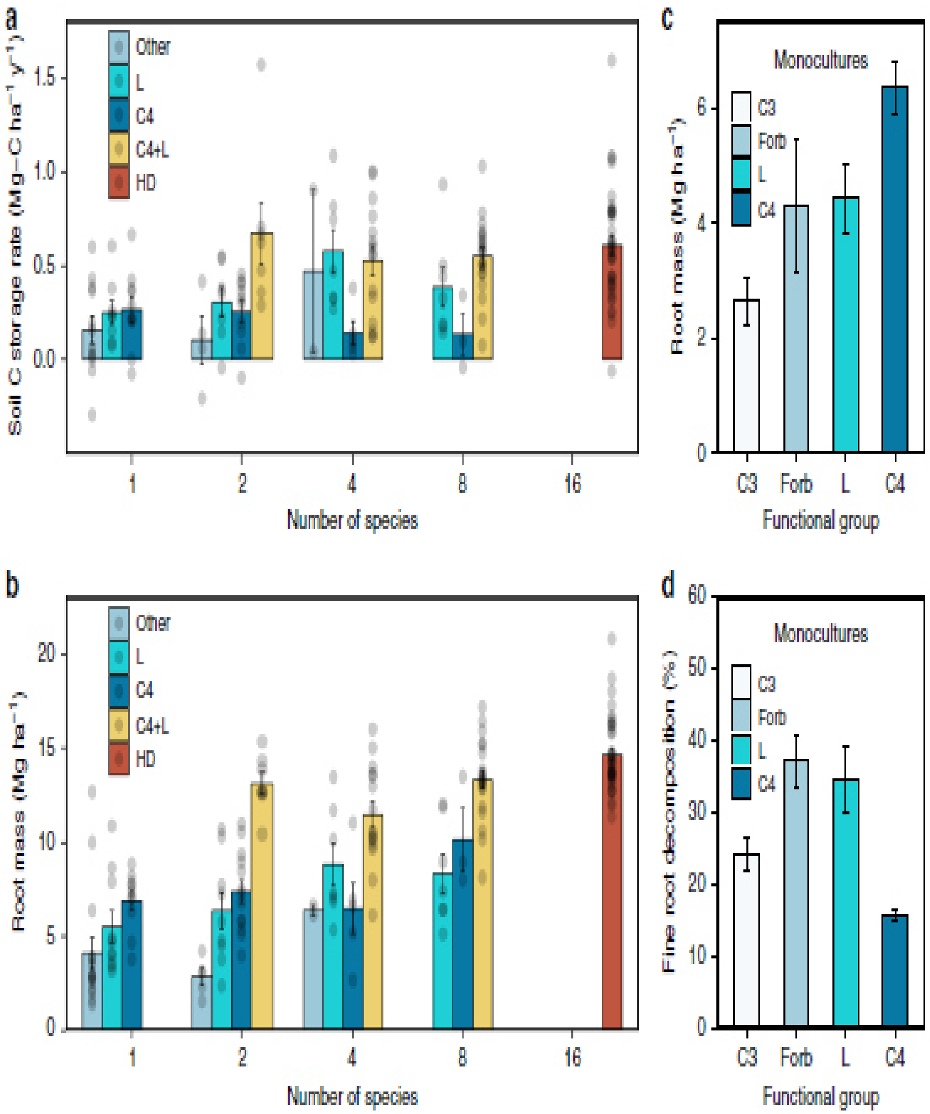


Fig. 4 Functional composition and traits influence root biomass and soil C storage. **a** Soil C storage rates over the entire 22 years for the 0–60 cm prof
b Mean root biomass for the 0–60 cm soil profile (average of 2006, 2015, and 2017). **c** Mean root biomass of different functional groups in monocult
plots (0–30 cm soil profile, average of 2006, 2015, and 2017). **d** Fine root decomposition percentage of different functional groups (measured after
10 months of field incubation, which included ~5 winter months[54]). In all panels, bars are means with standard errors. In **a** and **b**, dots indicate plot resu
C4=plots with at least one C4 but without legume; L=plots with at least one legume but without C4; C4+L=plots with at least one C4 and one legu
Other=forbs, C3, or woody; HD=16-species plots, which include both C4 and legume (of typically 3–4 species each). In **c** and **d** for monoculture plot
means legume

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