ASHRAE Hellenic Chapter

TEE

ENERGY IN BUILDINGS

EMEA 2024

Europe, the Middle East & Africa

FRIDAY - SATURDAY

NOVEMBER 22-23, 2024

@ 9:00-18:00

@ ATHENS GREECE

SESSIONS:

- SUSTAINABILITY
- HEALTH & SAFETY
- DECARBONIZATION
- TECHNICAL SOLUTIONS
- DIGITAL ENVIRONMENT
- POLICIES & LEGISLATION
- ENERGY EFFICIENCY FIRST
- RESILIENCE TO CLIMATE CRISIS

Carbon Sequestration

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Learning Objectives

After attendance, you should be able to:

1. State **why** decarbonization—reaching net zero—must be paired with carbon sequestration to limit the worst effects of climate change.
2. List three ways that **the Earth's natural systems already capture and store CO_2.**
3. Describe and contrast **three technologies for capturing CO_2 and either securely storing it or converting it to useful products**.
4. List the at least three **challenges** with Carbon Sequestration.

Outline of Presentation

I. Introduction

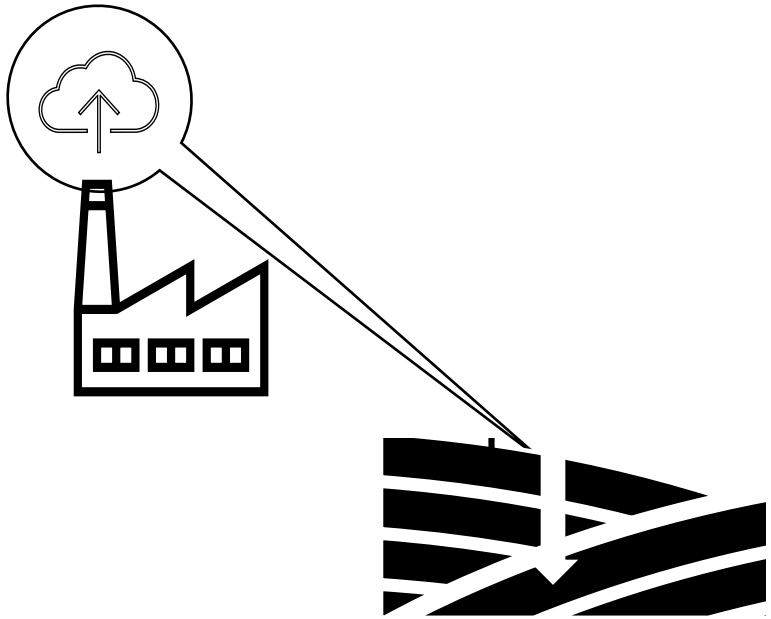
II. What is Carbon Sequestration?

III. Transportation and Storage of CO_2

IV. Challenges with Carbon Sequestration

V. Summary

VI. Recommended Sources



I. Introduction

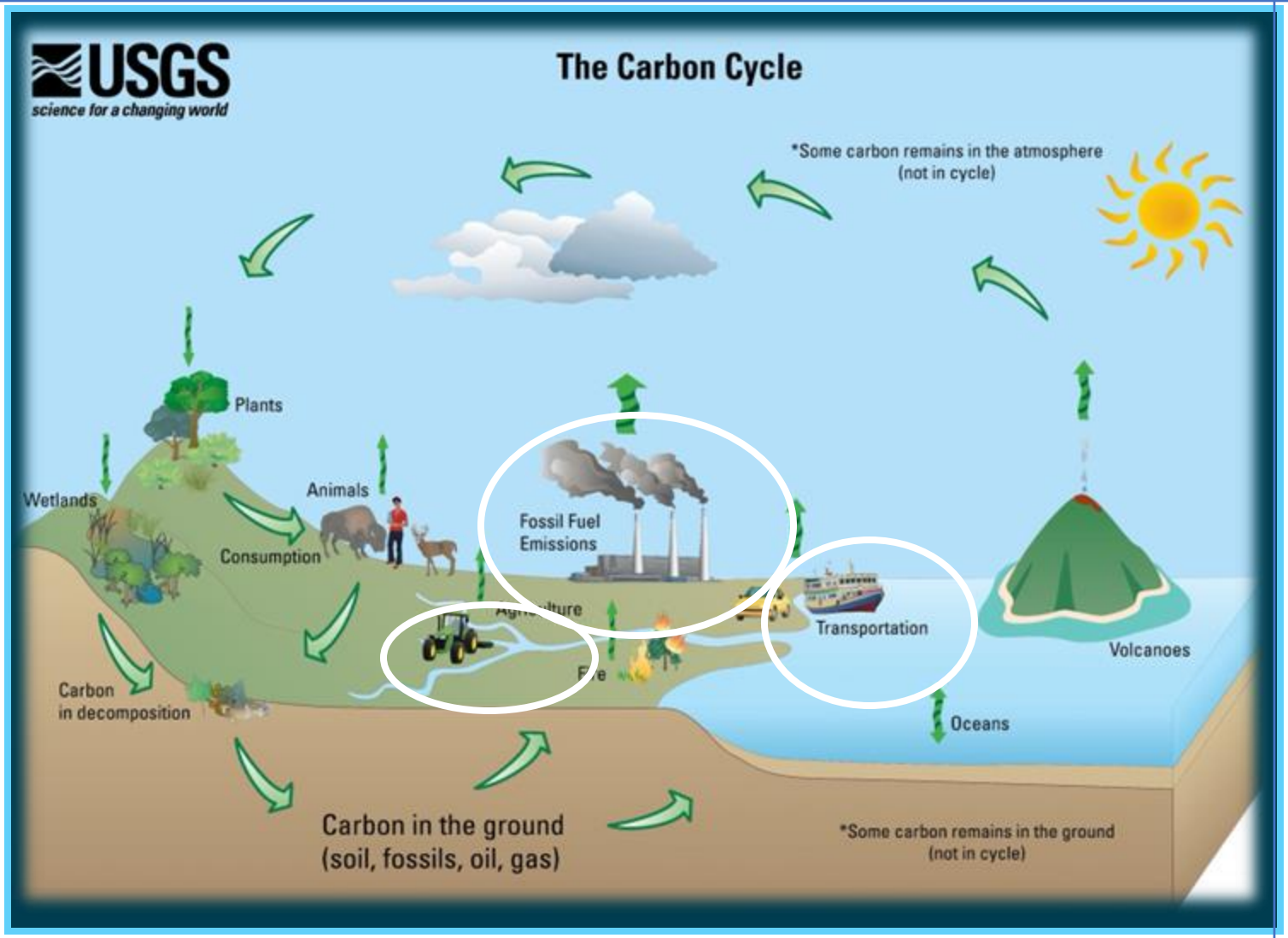
CARBON SEQUESTRATION

- **Not widely understood** and goes by many aliases
- Occurs (1) **naturally**, (2) as **anthropogenic-assisted** natural processes or (3) as **anthropogenic** technologies
- Extremely costly, but necessary?
- Safe to transport and able to be permanently stored?
- A contentious topic!
- ACHIEVING NET ZERO IS OUR FIRST PRIORITY**!**

I. Introduction

The **Carbon Cycle** describes the natural CO_2 capture, sequestration and release…and now includes the anthropogenic influence.

Note: Presenter added circles to indicate anthropogenic release.



https://www.usgs.gov/media/images/usgs-carbon-cycle

I. Introduction

Carbon Dioxide Removal "is a key element in scenarios that limit warming to 2°C …or 1.5°C…by 2100 …necessary to achieve net zero CO_2 and GHG emissions…."

Per IPCC https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

Carbon Budget

"the estimated cumulative amount of global carbon dioxide emissions …to limit global surface temperature to a given level above a reference period, taking into account global surface temperature contributions of other GHGs and climate forcers

https://www.ipcc.ch/sr15/chapter/glossary/

Global emissions since 1850: 2590 $GtCO_2e$

Beginning in 2024, remaining budget* in $GtCO_2e$ is:

- 275 for next 7 years to limit to 1.5°C
- 625 for next 15 years to limit to 1.7°C
- 1150 for next 28 years to limit to 2°C

IPCC AR6 WG1; https://doi.org/10.5194/essd-15-2295-2023; https://doi.org/10.5194/essd-15-5301-2023; http://www.globalcarbonproject.org/carbonbudget/

*50% likelihood

II. What is Carbon Sequestration?

IPCC Definition: *"The process **of storing carbon in a carbon pool**"*

https://www.ipcc.ch/sr15/chapter/glossary/

U.S. Geological Survey Definition: "[anthropogenic.] *process **of capturing and storing atmospheric carbon dioxide***"

https://www.usgs.gov/faqs/what-carbon-sequestration

…and there are many variations in its definition.

For this presentation, all processes used to capture and store or convert CO_2 to products will be collectively referred to as "Carbon Sequestration"

II. What is Carbon Sequestration?

A Broadly Used term for ***Anthropogenic*** Carbon Sequestration:

- **CARBON DIOXIDE REMOVAL (CDR):**

*"**Anthropogenic activities** removing carbon dioxide (CO_2) **from the atmosphere** and durably **storing it** in geological, terrestrial, or ocean reservoirs, or in products"*

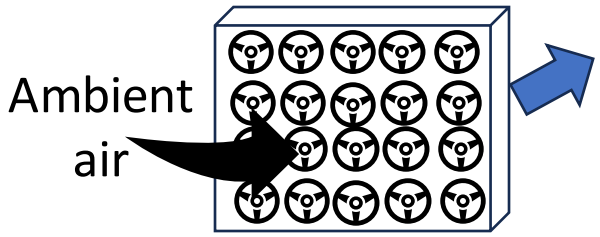
-- IPCC https://www.ipcc.ch/site/assets/uploads/2019/11/11_Annex-I-Glossary.pdf

Examples of CDR are shown on the next slide.

II. What is Carbon Sequestration?

Examples of CARBON DIOXIDE REMOVAL (CDR)

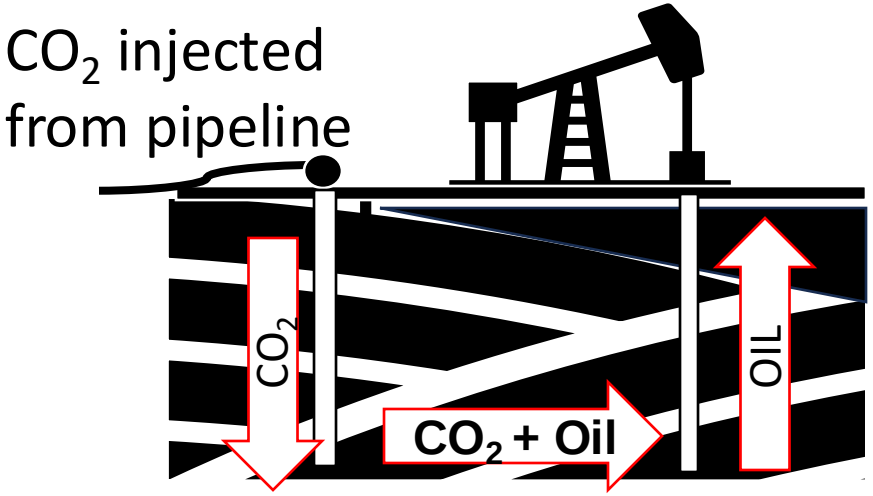
Direct Air Capture & Storage (DAC or DACS)



CO_2 is processed, injected into underground basalt and solidified within stone.

Enhanced Oil Recovery (EOR)

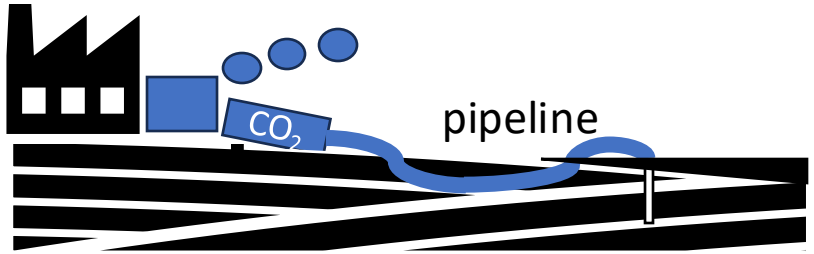
CDR only if CO_2 is from atmosphere and used CO_2 is durably stored



II. What is Carbon Sequestration?

Specific Term for industrial material/energy-related stream separations:

- **CARBON CAPTURE AND STORAGE (CCS):**



*"a process consisting of the **separation of CO_2** from industrial and energy-related sources, **transport** to a storage location and long-term **isolation** from the atmosphere."*

--2005 IPCC* *Special Report: Carbon Dioxide Capture and Storage*
https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_summaryforpolicymakers-1.pdf
--2022 IPCC *"CO_2 capture and storage is sometimes referred to as carbon sequestration. In [the 2022 IPCC] report, the term 'sequestration' is reserved for the enhancement of natural sinks of CO_2"*
https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf

II. What is Carbon Sequestration?

Specific Term for CO_2 conversion to products:

- **CARBON CAPTURE AND UTILISATION* (CCU):**

* The IPCC uses the English spelling for this word.

*"a process in which carbon dioxide (CO_2) is **captured** and the carbon then **used in a product**."*

--2022 IPCC Glossary

https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

Examples of CARBON CAPTURE AND UTILISATION (CCU):

CO_2 → PROCESS → **gaseous H_2 + solid carbon OR carbon nanofibers OR additive for concrete OR ???**

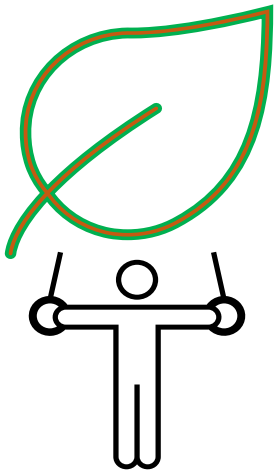
II. What is Carbon Sequestration?

SUMMARY: General Anthropogenic Carbon Sequestration Terms						
ACRONYM	**TERM**	**Remove or Captures CO_2 from atmosphere**	**Separates CO_2 from a product stream**	**Transports CO_2 to storage location**	**Durably stores CO_2**	**Process produces a product**
CDR	Carbon Dioxide Removal	X			X	
CCS	Carbon Capture & Storage		X	X	X	
CCU	Carbon Capture & Utilisation	X				X

"CCS and CCU can only be part of CDR methods if the CO_2 is biogenic or directly captured from ambient air and stored durably in geological reservoirs or products." IPCC AR6 2022

II. What is Carbon Sequestration?

Anthropogenic-Assisted Natural Carbon Sequestration Term :



- **NEGATIVE EMISSIONS TECHNOLOGIES (NETs):**

*"Activit[ies] or mechanism[s] that result in… removal of greenhouse gases (GHGs) **from the atmosphere** by deliberate **human activities**, i.e., in addition to the **removal that would occur via natural carbon cycle processes**"*

--IPCC https://www.ipcc.ch/site/assets/uploads/2019/11/11_Annex-I-Glossary.pdf

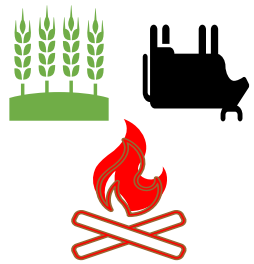
Examples of NETs are shown on the next several slides.

II. What is Carbon Sequestration?

Examples of Negative Emissions Technologies (NETs)

1. Afforestation and Reforestation (AR)

2. No-till farming

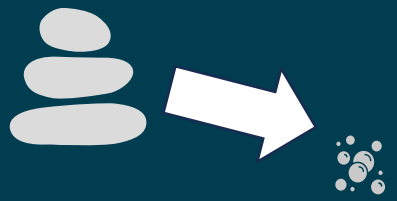


3. Conversion of biomass to biochar added to soil
4. Adding iron to the ocean (“encourages biological activity to pull CO_2 out of the air”)

II. What is Carbon Sequestration?

Examples of Negative Emissions Technologies (NETs)

5. Enhanced Rock Weathering (ERW)



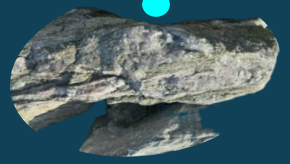
or

'clean' mining powder waste is spread over agricultural soil to accelerate the natural process shown at right

1

$CO_2 + H_2O \rightarrow H_2CO_3$

Carbonic Acid



Calcium Carbonate — Calcium ion — Bicarbonate

$H_2CO_3 + CaCO_3 \rightarrow Ca^2 + 2HCO_3$

2

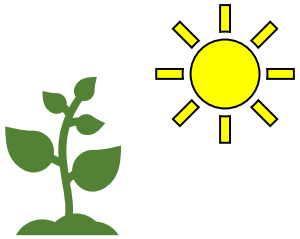
Rock breaks down and washes away to rivers….and eventually flows to the ocean where resulting CO_2 sinks, and is sequestered.

$2HCO_3 \rightarrow CO_2 + H_2O$

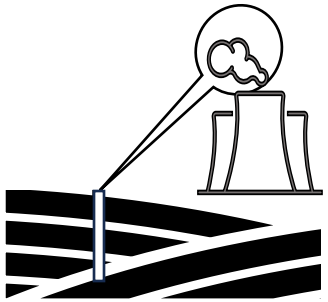
II. What is Carbon Sequestration?

Examples of Negative Emissions Technologies (NETs)

6. Bioenergy with CCS (BECCS)



- **Biomass source**: plants use atmospheric CO_2 and sunlight through photosynthesis to create glucose and oxygen. Animals eat plants.
- **Biomass:** wood, animal manure, crops and agricultural remnants, sewage, animal fats and vegetable oils.
- Conversion of **biomass to energy** by burning, or **conversion to fuels** by biological, chemical or thermochemical processes and **CO_2 is captured from the biomass-fueled power plant exhaust.**



III. Transportation and Storage of CO_2

Transportation of CO_2 is provided by:

- Pipelines
- Trucks
- Trains

Concerns by some that CO_2 could leak from transportation sources!

Concerns by some that CO_2 could leak from some storage areas!

CO_2 can be sequestered by:

- Injection into **geologic formations**
- Injection into **deep levels of the ocean**
- Mineralized into **rock**
- Conversion into **product**

IV. Challenges with Carbon Sequestration

Costs are very high; most processes require significant energy:

Estimated Cost Examples in 2023

$5-$240/t CO_2	Afforestation & Reforestation
$10-$375/t CO_2	Biochar
$15-$130/t CO_2	Carbon Capture & Storage*
$15-$400/t CO_2	Bioenergy combined with Carbon Capture & Storage
$50-$200/t CO_2	Enhanced Weathering
$100-$345/t CO_2	Direct Air Capture*

https://www.statista.com/statistics/1304575/global-carbon-capture-cost-by-technology/

Estimated Costs for Industrial Processes in 2019

$15-$25/t CO_2 - Industrial Processes producing highly concentrated CO_2 streams*
[Note that this CCS using concentrated streams results in lower 'upper level' costs.]

https://www.iea.org/data-and-statistics/charts/current-cost-of-co2-capture-for-carbon-removal-technologies-by-sector

*Anthropogenic process. Others are NETs.

IV. Challenges with Carbon Sequestration

Capacities are lacking:

"[Carbon Capture, Utilization and Storage] ***CCUS facilities currently capture more than 50 Mt* CO_2 annually"***

"total amount of CO_2 that could be captured in 2030 [would be] around 435 million tonnes (Mt) per year and ***announced storage capacity to around 615 Mt of CO_2 per year…***

[This is] *still just around 40% …of the circa 1 Gt CO_2 per year which is captured and stored in the Net Zero Emissions by 2050 (NZE) Scenario."*

https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage

*50 Mt = 0.05 Gt The global emissions for 2023 were 57.1 ± 5.4 Gt CO_2e

IV. Challenges with Carbon Sequestration

Pulling CO_2 from the atmosphere is inefficient and energy-intensive:

For Direct Air Capture, 300 times larger air volumes must be processed than that from a flue gas stream using CCS to capture the same amount of CO_2.

Herzog, Howard J. 2018 *Carbon Capture*. MIT Press. p. 132.

"In the IEA Net Zero Emissions by 2050 Scenario, ***direct air capture technologies capture more than 85 Mt of CO_2 in 2030 and around 980 $MtCO_2$ in 2050****, requiring a large and accelerated scale-up from almost 0.01 $MtCO_2$ today…*

…Currently 18 direct air capture facilities are operating in Canada, Europe and the United States. ***The first large-scale direct air capture plant of up to 1 $MtCO_2$/year is in advanced development and is expected to be operating in the United States by the mid-2020's."***

https://www.iea.org/reports/direct-air-capture-2022

V. Summary

- The IPCC stated that Carbon Capture and Storage must be paired with decarbonization to limit (or return to, if overshot) 1.5°C or 2.0°C above preindustrial temperature levels.
- Carbon Sequestration is very expensive, energy-intensive and inefficient—especially Direct Air Capture.
- There are concerns regarding the safety of transporting CO_2 and the permanence of storage options.
- The current (and near-future projected) capacity of Carbon Sequestration is insufficient to meet the projected carbon budget.

VII. Recommended Sources

IEA Database: "covers all CO_2 capture, transport, storage, and utilization projects worldwide that have been commissioned since the 1970s, and have an announced capacity of more than 100 000 t per year (or 1 000 t per year for direct air capture facilities)" https://www.iea.org/data-and-statistics/data-product/ccus-projects-database

Smith School of Enterprise and the Environment, University of Oxford: maintains a free data portal on the state of Carbon Dioxide Removal https://www.stateofcdr.org/

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