POTENTIALS & COST OF CO_2 REMOVAL OPTIONS

CHIRAG BHIMANI


SEE? NATURE EMITS FAR MORE THAN US.
LOOK BEHIND YOU!
33
439
287
451
293
Human CO_2 emissions
Natural CO_2 emissions
Natural CO_2 absorptions

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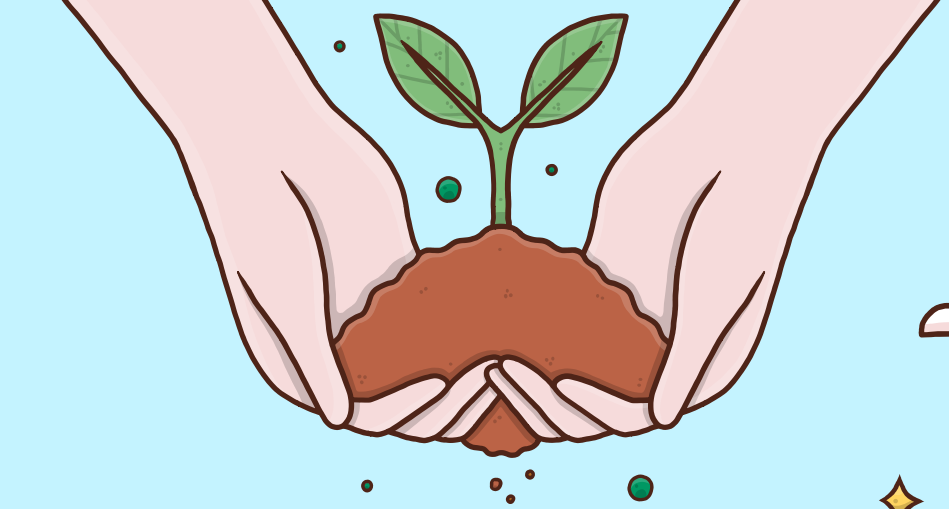


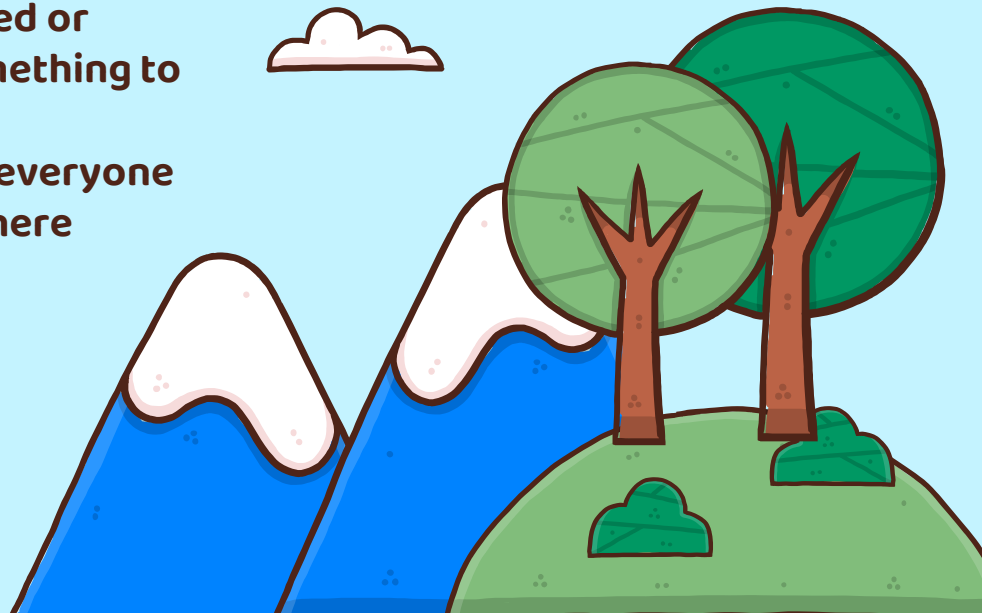
01
INTRODUCTION

INTRODUCTION

- To meet the 2°C target goals under the 2015 Paris Agreement, as well as to ameliorate concerns regarding the viability of pledges, Carbon Dioxide Removal (CDR) options provide the potential to offset carbon dioxide (CO_2) emissions.
- CDR is different from other climate mitigation strategies as it aims to increase the rate of negative emissions to achieve “beyond carbon-neutral" rather than reduce net GHG emissions to zero to achieve a "carbon-neutral" state.
- The process of CDR can be achieved through natural processes, such as photosynthesis, weathering of silicate rock, and absorption by the ocean.
- The enhanced natural processes and development of options which capture and sequester or utilize CO_2 are required to accelerate the rate of CDR and reach negative net carbon emissions in the future.

WHY WE SHOULD BE CONCERNED...

- Climate change may seem slow, but it is unnervingly fast.
- We cannot postpone dialogue and action.
- Regardless of where we live – developed or developing countries – we all have something to lose.
- Thus, we all have something to do and everyone must act because CO_2 emissions anywhere threaten development everywhere.



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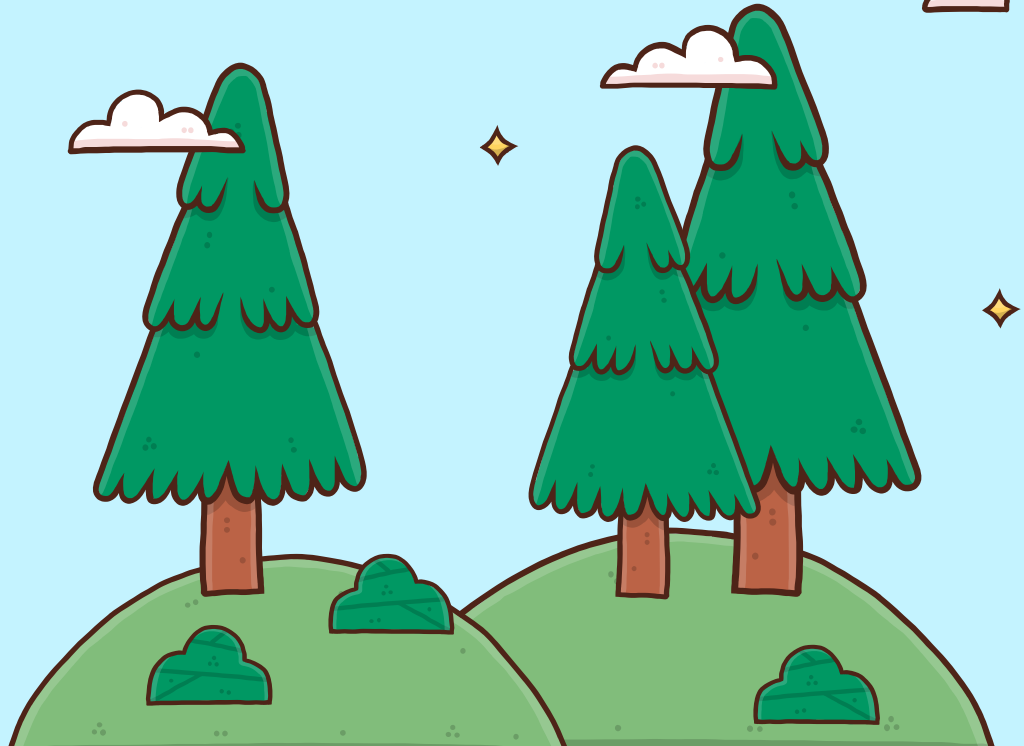
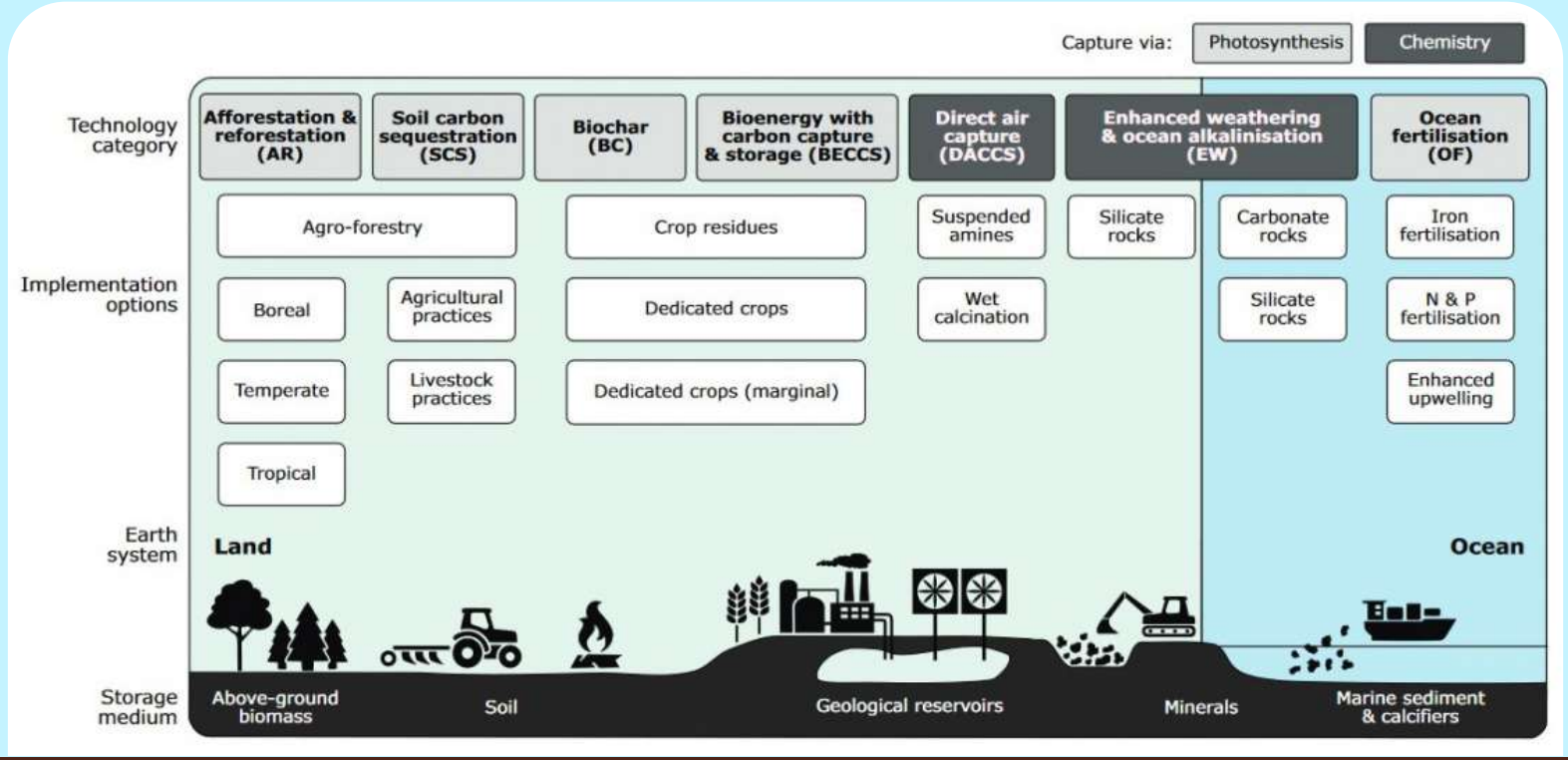
METHODS OF CO_2 REMOVAL



METHODS OF CO_2 REMOVAL



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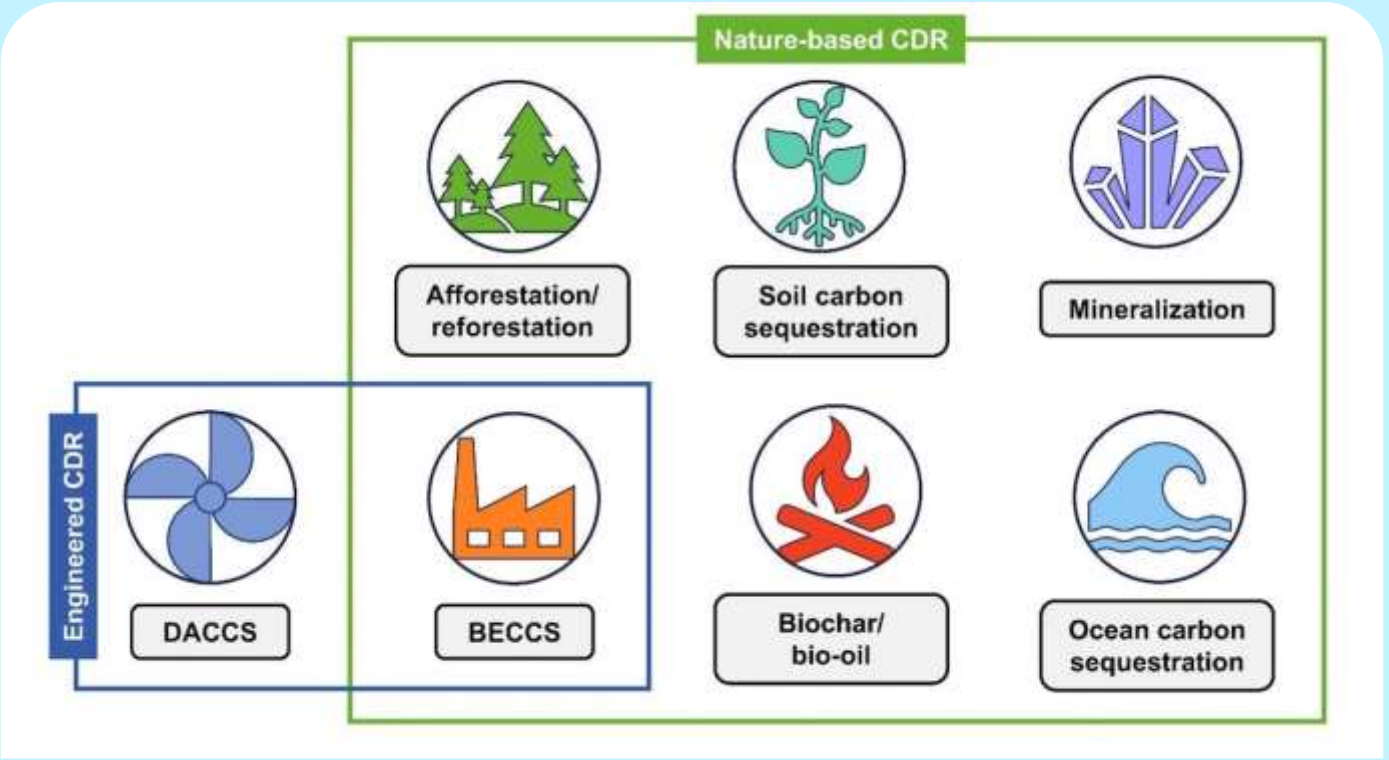


METHODS OF CO_2 REMOVAL

Nature Based CDR

- They are cheap and low-tech, and include soil carbon sequestration—modern farming ways that sequester carbon dioxide—and afforestation.
- The latter involves planting trees where there were previously none, increasing the Earth's capacity to convert carbon dioxide in oxygen.
- While this method is cheap and provides positive effects on biodiversity, it is also very vulnerable, for instance to fires.
- "Natural solutions also have some general downsides, such as that they cannot be scaled up sufficiently due to natural limitations. Also, you need to ensure that a large number of stakeholders is on the same page, which can be quite challenging."

METHODS OF CO_2 REMOVAL

Engineered CDR

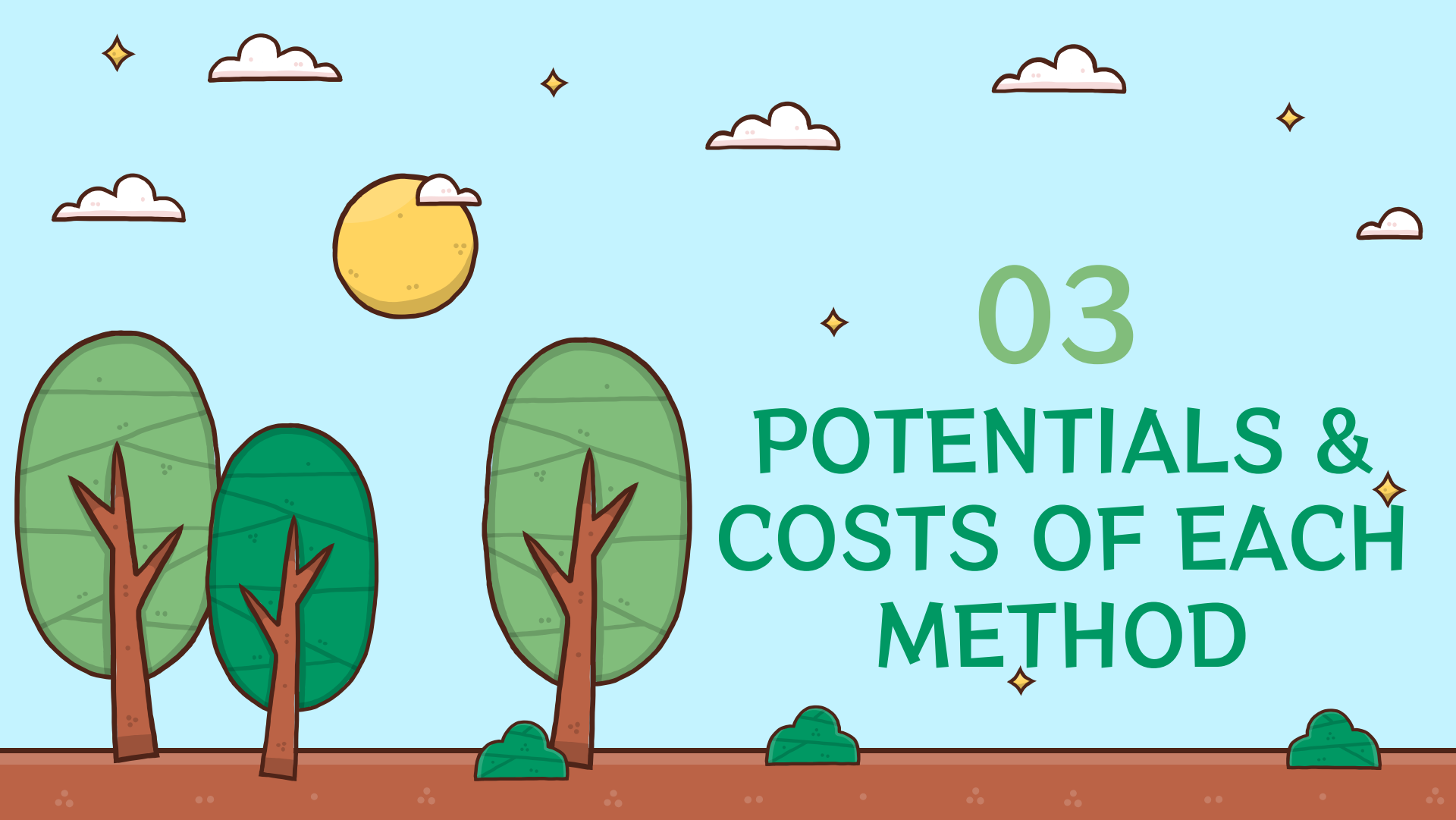
- They are more high-tech. e.g. Direct Air Capture, in which gigantic vent-like machines suck carbon dioxide straight out of the air, which can then be locked away underground.
- "The problems with these techniques are that most of them are not fully developed yet, and the costs can be very high.
- Some techniques pose severe side effects, such as the so-called BECCS wherein bioenergy crops are used that extract CO_2 from the air as they grow. Afterwards, they are burnt for energy and capture the CO_2 that is released to lock it underground. This method can be effective, but threatens our food security and the already alarming biodiversity loss."

METHODS OF CO_2 REMOVAL

CDR Options	Definition	Readiness Level
Afforestation/ Reforestation (AR)	Afforestation/Reforestation refers to land managementmethodologies that involve intentional forest management techniques to sequester and store CO_2 over a prolonged period.	Established
Soil Carbon Sequestration	Soil Carbon Sequestration is a land management technique that aims to increase the amount of carbonstored in soil organic matter as well as in inorganic forms within the soil.	Demonstrated
Biochar	Biochar creates charcoal derived from biomass througha process called pyrolysis, which heats biomass to between 300°C and 800°C in a low oxygenated environment.	Demonstrated
Terrestrial BECCS	The BECCS process takes advantage of the carbon dioxide removal abilities of photosynthesis through thegrowth of terrestrial biomass with the additional capture of CO_2 during the production of energy products.	Demonstrated

METHODS OF CO_2 REMOVAL

CDR Options	Definition	Readiness Level
Aquatic BECCS	Aquatic BECCS absorbs CO_2 via plant growth in the ocean and then uses the harvested aquatic biomass togenerate energy with capture and subsequent storage of CO_2.	Speculative
Ocean Fertilization	Ocean fertilization purposefully introduces specific nutrients into the ocean to stimulate growth in marineorganisms (phytoplankton), thus removing CO_2 from the atmosphere via photosynthesis by ocean organisms.	Speculative
Accelerated Weathering	Accelerated weathering refers to the geochemical process by which naturally-occurring carbonate andsilicate weathering are accelerated on land and in marine environments.	Speculative
Direct Air Capture (DAC)	DAC systems separate CO_2 directly from the atmosphere through chemical adsorption.	Speculative



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POTENTIALS & COSTS OF EACH METHOD

AFFORESTATION AND REFORESTATION

- Afforestation and Reforestation (AR), an established CDR option, is a commonly referenced land management methodologies that removes CO_2 from the atmosphere through photosynthesis and store the carbon within forest biomass.
- Although AR has benefits such as creating additional ecosystem services, its major challenge is the question of permanence, related to natural disasters and deforestation as well as competition over land area.

POTENTIAL & COST

- Potential to capture and store between 0.01 – 14 GtCO2e/year at a cost between $2 - $100/tCO2e
- The median values of this wide range suggest an approximate CDR potential of 1.1 GtCO2e/year at $30/t CO2e

BIOCHAR

- Biochar, a demonstrated CDR option, is produced when biomass, which takes in carbon through photosynthesis, is heated to between 300°C and 800°C in a low-oxygen environment. The end product is a carbon-rich char, commonly known as charcoal. This char can then be used as a soil amendment and has been used for thousands of years by some pre-industrial agricultural communities.
- Biochar is considered a form of carbon storage because the char decomposes much slower than the surrounding biomass when added to soils.

POTENTIAL & COST

- Potential to capture and store between 0.03 – 1 GtCO2e/year at a cost between $150 - $670/tCO2e

BIOCHAR

- Although low-tech techniques to produce biochar have been around for millennia, research is underway to develop technologies for efficient large-scale production.
- The greenhouse gases released during the production process could become significant for large-scale production.
- There is also a limit to the amount of biochar that can be added to soils, and in some cases, biochar was shown to have adverse effects on crop yields.

POTENTIAL & COST

- Median range of CDR by Biochar is 0.2 $GtCO_2e$/year at an approximate cost of \$40/tCO_2e.

SOIL CARBON SEQUESTRATION

- Soil carbon sequestration, a demonstrated CDR option, entails management of pastures and cropland to increase the carbon stored in the soil.
- Evaluation suggests an approximate cost of $8/tCO2e but due to limited use cases, cost cannot be accurately forecasted at this time. Because soil carbon sequestration is based on the natural carbon cycle, challenges exist in measuring the net carbon sequestered over large areas and ensuring its permanence in the soil.

POTENTIAL & COST

- Potential to capture and store between 0.1 – 13 GtCO2e/year at a cost between $5.50 - $11/tCO2e.
- The median CDR potential is 1.3 GtCO2e/year

BIOENERGY WITH CC&S

- BECCS, a demonstrated option, harvests biomass for conversion into electricity or biofuels through combustion, gasification, fermentation or other processes.
- The biogenic CO2 released during combustion and processing is captured rather than emitted to the atmosphere using technologies like those designed for fossil fuel carbon capture and storage (CCS).
- Extracting more than 12 GtCO2 from the atmosphere a year results in large increases in costs.

POTENTIAL & COST

- Potential to capture and store between 0.04 – 32 GtCO2e/year at a cost between $20 and $440/tCO2e

BIOENERGY WITH CC&S

- The technology for generating electricity and capturing CO_2 from power plants already exists and BECCS benefits from those previous investments.
- BECCS is widely assumed in Integrated Assessment Model (IAM) scenarios that simulate ways to limit global warming to 2°C.
- There is concern about dedicated energy crops increasing food prices and decreasing biodiversity.
- BECCS has come under scrutiny recently as questions emerge about whether BECCS is carbon negative, neutral or positive.

POTENTIAL & COST

- The median values of BECCS CDR potential and costs are 9 GtCO2e/year at $60/tCO2e

DIRECT AIR CAPTURE

- DAC, a speculative CDR option, involves the use of man-made structures to capture CO2 from ambient air and concentrate it through chemical bonding.
- Bonds are formed by either an aqueous solution or a porous ion charged solid filter.
- While these systems are undergoing engineering development, no large-scale demonstration project has been undertaken.
- Wide variances in the removal potential and economic estimates exist due to the largely speculative nature of DAC and the range of assumptions used in the evaluation.

POTENTIAL & COST

- Potential to capture and store between 0.0004 – 16 GtCO2e/year at a cost between $30 - $1,050/tCO2e.

DIRECT AIR CAPTURE

- DAC benefits from a small geographic footprint compared to other CDR options and can be built near geologic storage options to reduce transport costs.
- The high cost of capture is a significant challenge to overcome and is attributed to high energy requirements.
- There is a consensus that DAC will not be a feasible option until mid-century after the energy sector has been de-carbonized.

POTENTIAL & COST

- DAC has a median cost of $345/tCO2e with a removal potential of 1 GtCO2e/yr.

ACCELERATED WEATHERING

- Accelerated weathering, a speculative CDR option, is a set of CO_2 removal techniques that accelerate the chemical reaction of CO_2 with silicate-based minerals such as olivine, serpentine, and wollastonite.
- In-situ accelerated weathering involves exposing these minerals to atmospheric gases over a large land area.
- Alternatively, carbon mineralization mixes industrial waste such as cement kiln slag or coal fly ash with CO_2 in a saline solution in a controlled reaction facility.

POTENTIAL & COST

- Potential to capture and store between 0.001 – 18 $GtCO_2e$/year at a cost between \$20 - \$540/tCO_2e
- Median estimates of 3.7 $GtCO_2e$/year at \$70/tCO_2e.

OCEAN FERTILIZATION

- Ocean fertilization, sometimes known as ocean nourishment, is a speculative CDR option that purposefully introduces specific nutrients into the ocean to stimulate growth in marine microscopic organisms (phytoplankton), thus speeding up the rate at which CO_2 is removed from the atmosphere via photosynthesis by ocean organisms.
- A claimed benefit of ocean fertilization is it will not compete for land. However, little is known about large-scale, long-term impacts of adding millions of tons of iron, nitrogen, or phosphorous to the ocean.

POTENTIAL & COST

- Potential to capture and store between 1 – 11 GtCO2e/year at a cost between $10 - $290/tCO2e
- Median estimates of 4 GtCO2e/year at an approximate cost of $30/tCO2e

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CONCLUSION

CONCLUSION

- The CDR options discussed covered terrestrial and aquatic, above-and-below-ground, simple and complex, and ready to implement today and futuristic options.
- The biggest takeaway is that this set of CDR options offer enough removal potential to warrant equal consideration to other emission reduction measures.
- All options face limitations and uncertainties so a diverse portfolio of options should be pursued, and implementation should occur in a staged manner, in which options are implemented as they become feasible.

CONCLUSION

- Terrestrial options such as Afforestation & Reforestation, accelerated weathering, and BECCS require large amounts of land.
- The aquatic CDR options and DAC can help offset some of the land requirements.
- High-cost options such as DAC can be strategically implemented and low- cost options such as Afforestation & Reforestation can offset costs.
- As these CDR options will be working in tandem, it is important to understand the comparative economics and CO2 removal potential.

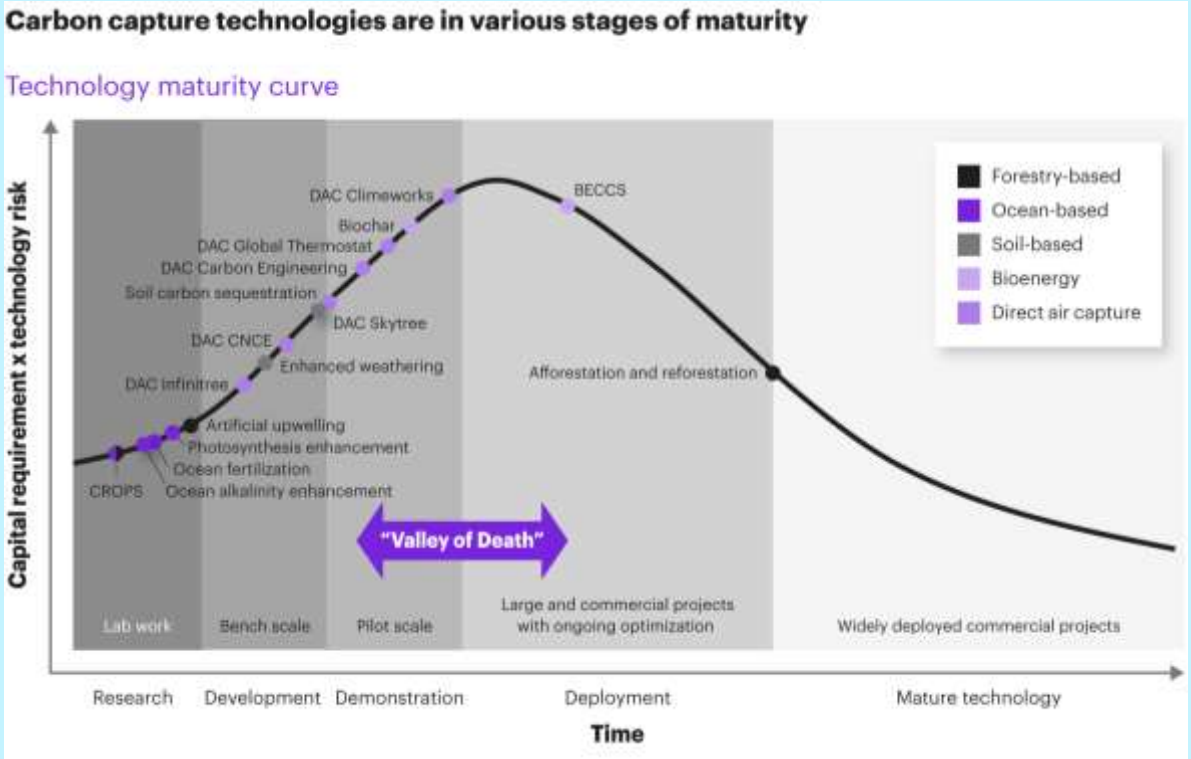
CONCLUSION

- Among the demonstrated CDR options, the magnitude of CDR potential identified for BECCS appears to greatly exceed that of soil carbon sequestration and biochar; however, this is due to the highly speculative large-scale BECCS implementation that has been simulated in many Integrated Assessment Model (IAM) scenario analyses.
- Regarding cost, soil carbon sequestration appears to be the least expensive option with its very tight and low range of published economic estimates.

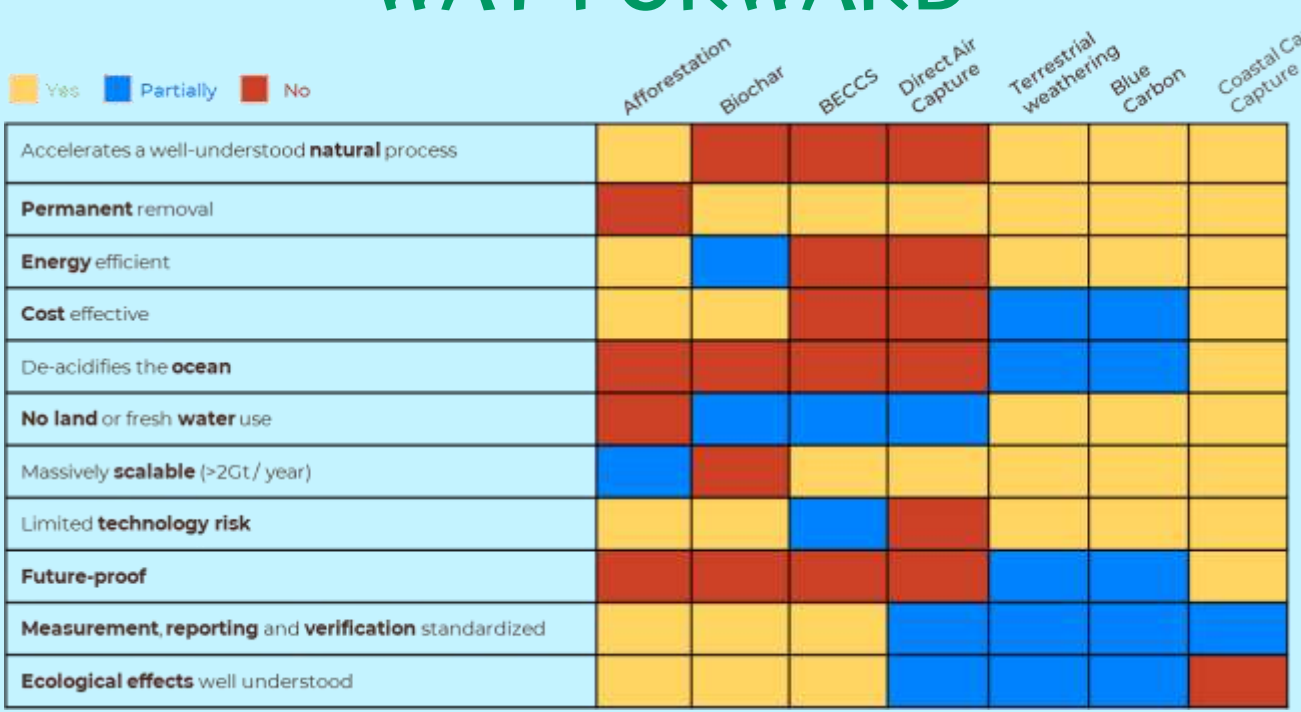
CONCLUSION

- Biochar offers the added benefit of generating revenue through improved crop productivity, which is why the low end of its estimates includes a negative cost.
- The speculative options vary greatly regarding the carbon removal potential.
- All speculative options have modest low and median/selected values and, with the exception of ocean storage, have large maximum estimates.

CONCLUSION


Carbon capture technologies are in various stages of maturity
Technology maturity curve
Capital requirement x technology risk
DAC Climeworks
BECCS
Biochar
DAC Global Thermostat
DAC Carbon Engineering
Soil carbon sequestration
DAC Skytree
DAC CNCE
Enhanced weathering
DAC Infinitree
Afforestation and reforestation
Artificial upwelling
Photosynthesis enhancement
Ocean fertilization
CROPS
Ocean alkalinity enhancement
"Valley of Death"
Forestry-based
Ocean-based
Soil-based
Bioenergy
Direct air capture
Lab work
Bench scale
Pilot scale
Large and commercial projects with ongoing optimization
Widely deployed commercial projects
Research
Development
Demonstration
Deployment
Mature technology
Time

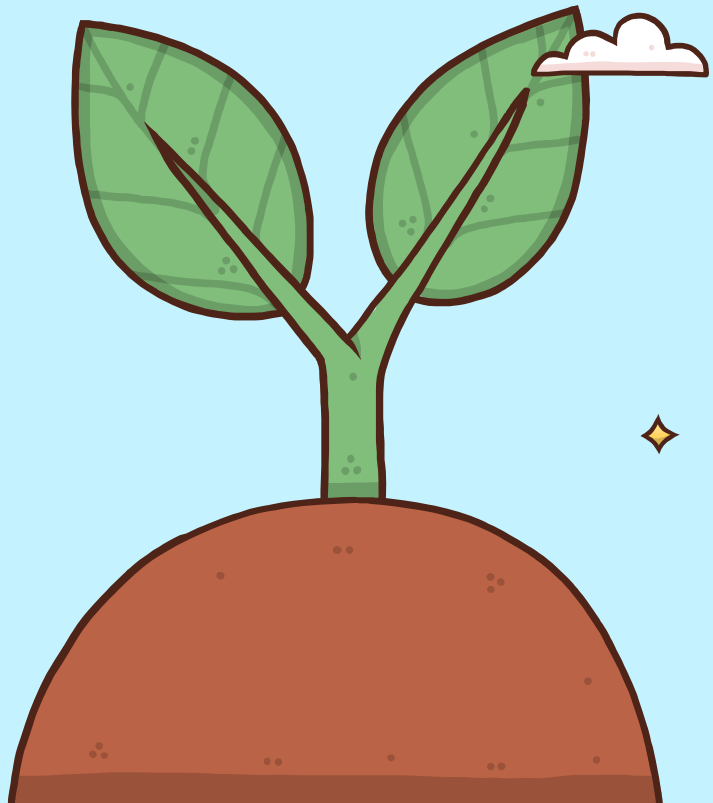
WAY FORWARD



CARBON REMOVAL METHOD COMPARISON

"We really need to kick the carbon habit and stop making our energy from burning things. Climate change is also really important. You can wreck one rainforest then move, drain one area of resources and move onto another, but climate change is global."

— **SIR DAVID ATTENBOROUGH**
Natural World Broadcaster



THANKS

Do you have any questions?

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WHOA!