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Advancing Carbon Dioxide Removal: International Collaboration and MRV Innovations at AIST-GZR

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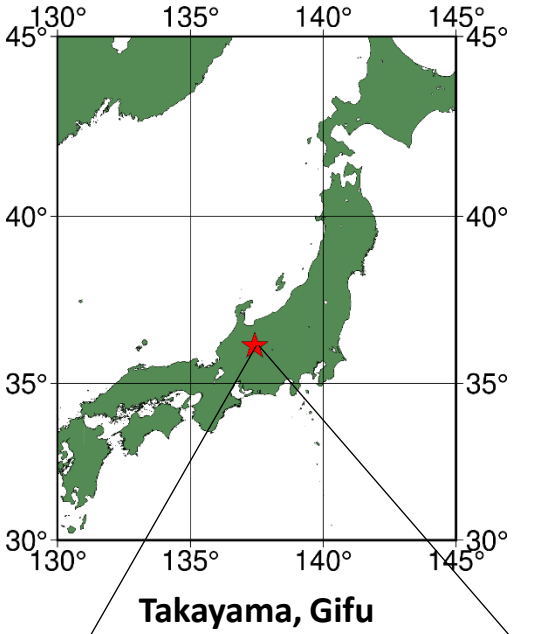
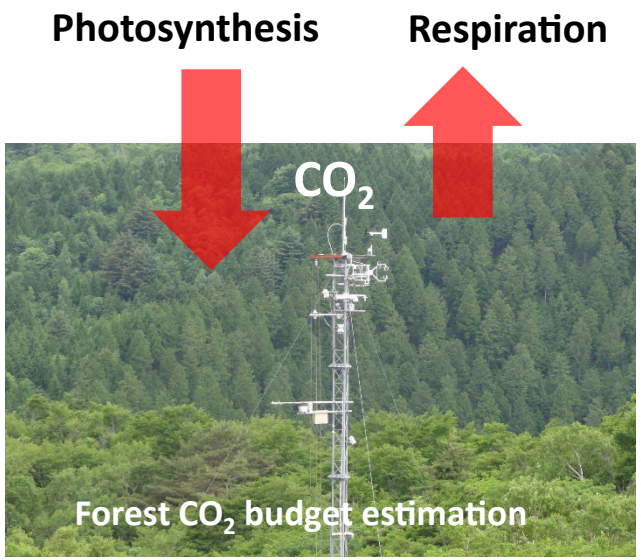
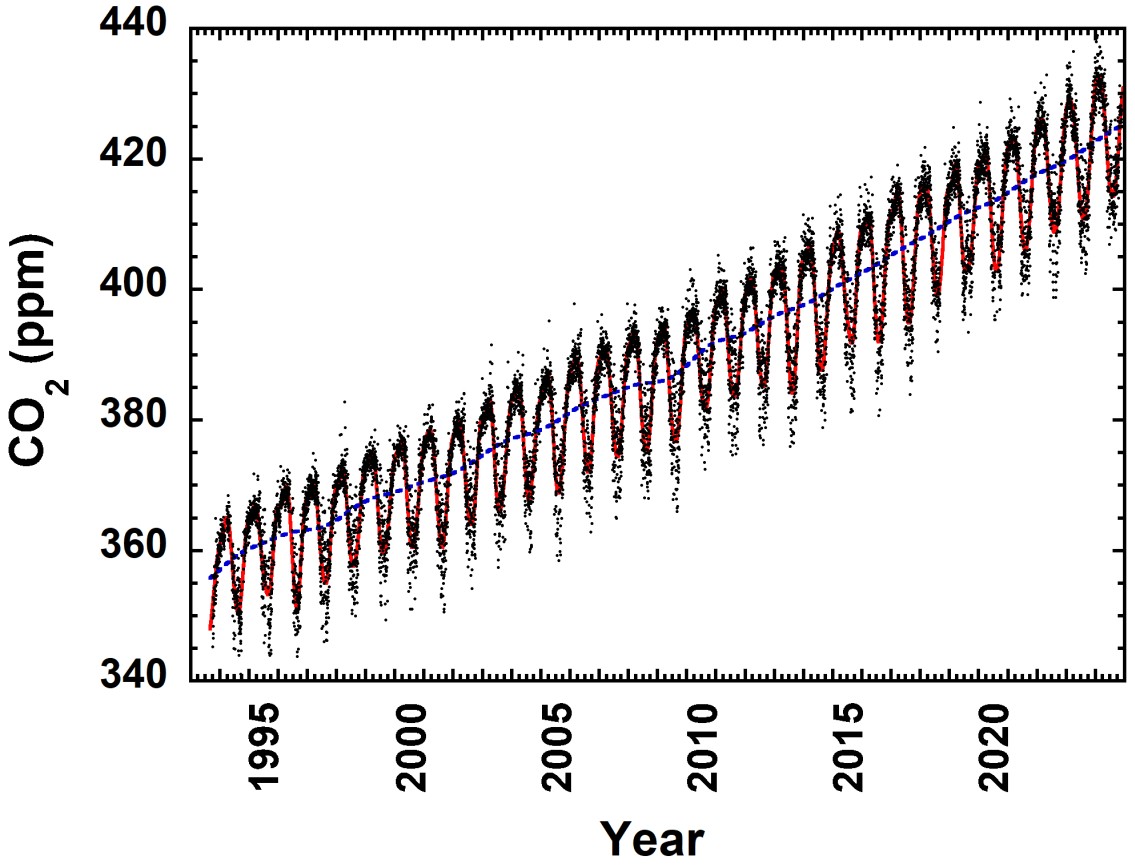
Atmospheric CO_2 level and global CO_2 budget

AIST's atmospheric CO_2 observation

- **AIST has been observing atmospheric CO_2 in Takayama since 1993 to estimate CO_2 uptake by the forest ecosystem – the world's second-longest record of forest CO_2 budget –**
- **Atmospheric CO_2 shows a long-term increase along with a noticeable seasonal variation.**



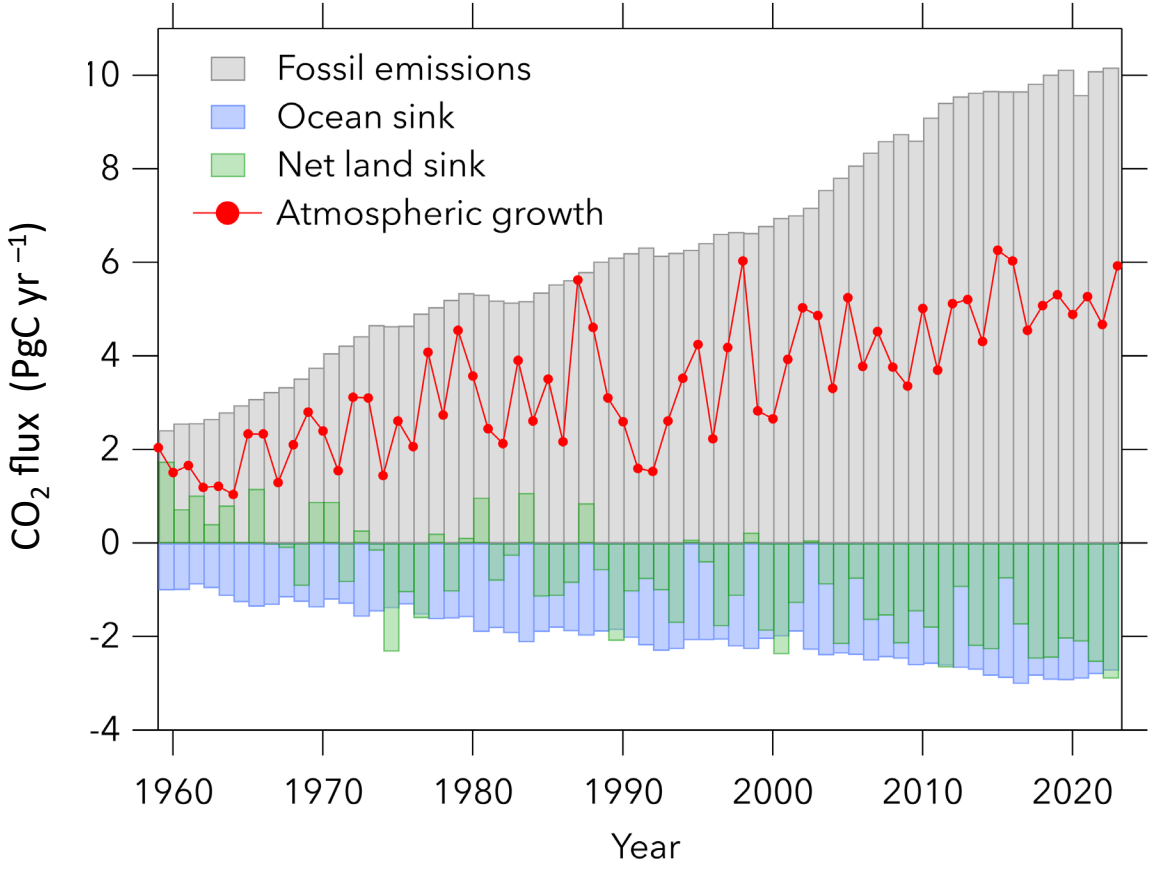


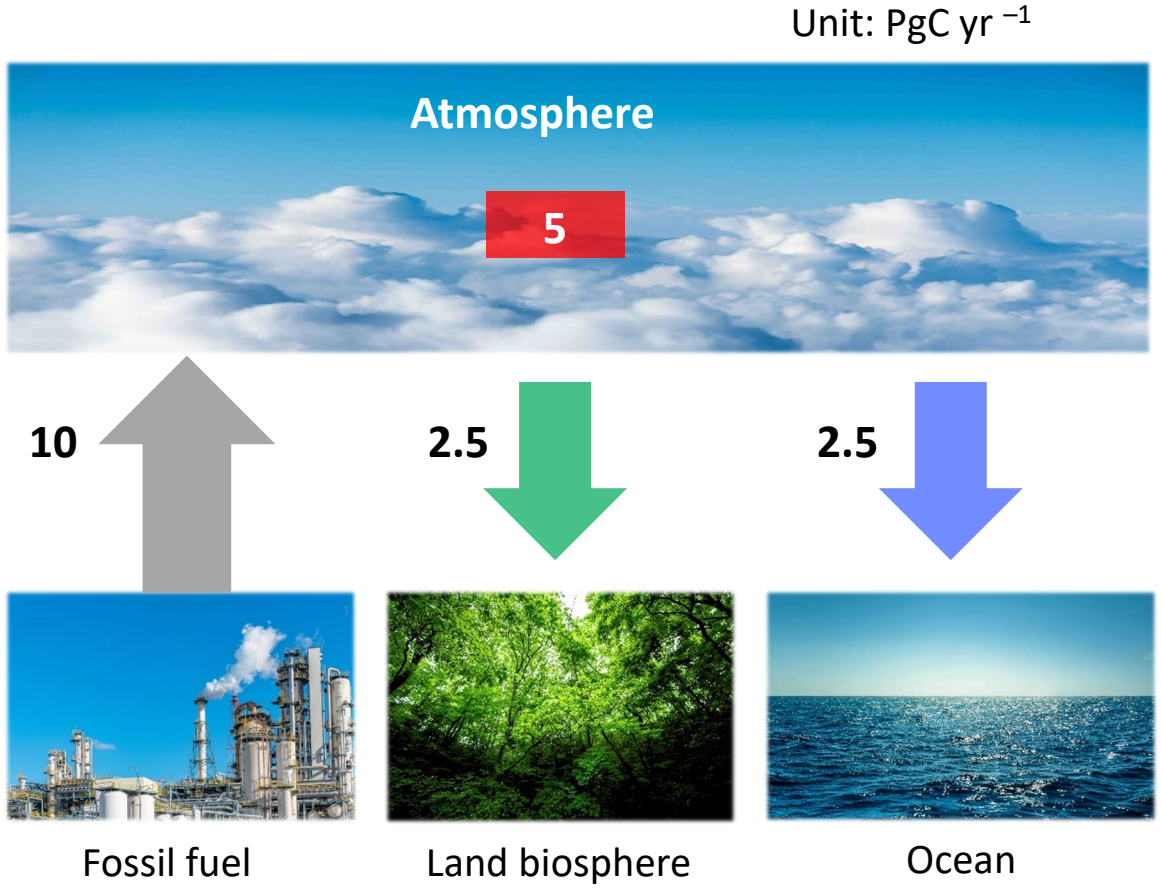


Sources: Updated from Murayama et al. (2010). J. Geophys. Res., 115(D17), https://doi.org/10.1029/2009JD013626.
Murayama, S. et al. (2024). J. Geophys. Res. Biogeos., 129, https://doi.org/10.1029/2023JG007769.

Global CO_2 budget – fate of fossil fuel CO_2 –

- **About half of the CO_2 from fossil fuels is absorbed by land and oceans, while the other half remains in the atmosphere.**
- **Fossil emissions have their own inventory, but atmospheric CO_2, along with the uptake of CO_2 by land and ocean, should be measured through observations.**





Source: Global Carbon Project. (2024). Supplemental data of Global Carbon Budget 2024 (Version 1.0) [Data set]. https://doi.org/10.18160/gcp-2024

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Our efforts on CDR

CDR: Carbon Dioxide Removal

MRV: Measurement, Reporting and Verification

What is CDR technology?

Reducing CO_2 emissions from fossil fuels has its limitations. To reach CN, CDR is essential.

CO_2

Global Carbon Cycle (Land & Ocean)

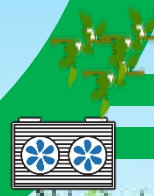
Natural approaches

Afforestation and Blue Carbon

Artificial approaches

CDR can remove CO_2 artificially from the global carbon cycle.

MRV is necessary.



Biomass

DAC

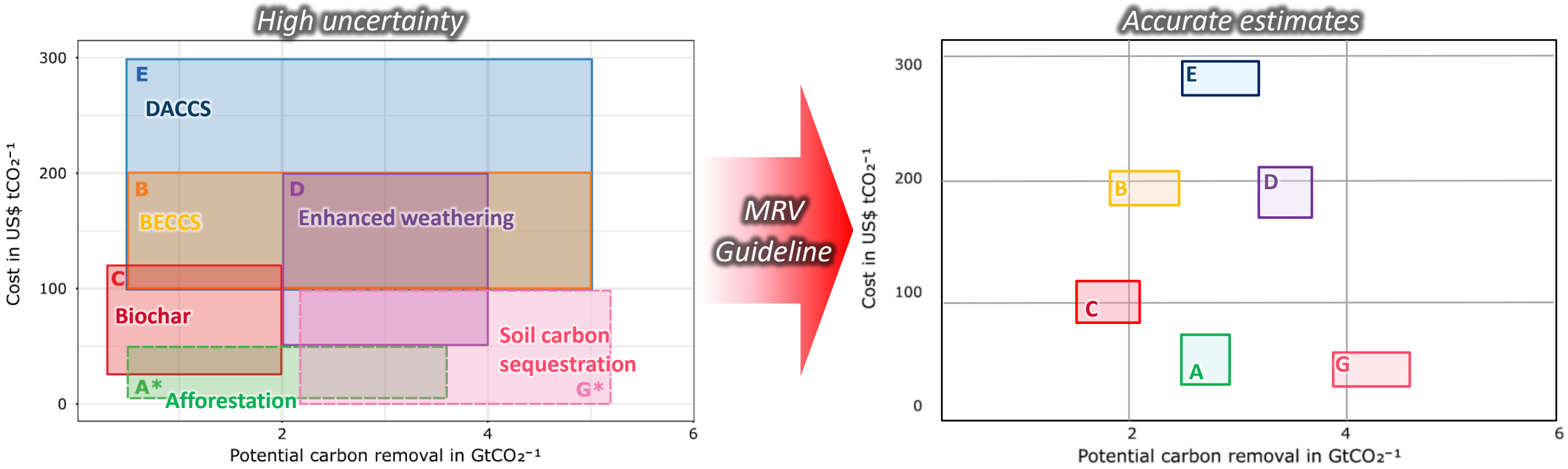
CCS

Biochar

Carbonates

CDRs potential and their cost: Importance of MRV

- CDRs involve high uncertainty, because there are no global common guidelines for their assessment.
- As CDR credits are being considered worldwide, establishing MRV schemes and common assessment methodology (guideline) has become a global challenge for accurately estimating the potential and costs of CDRs.



Source: Sabine Fuss, Negative emissions—Part 2: Costs, potentials and side Effects, *Environ. Res. Lett.* 13 (2018)

Example of the potential and cost estimates of CDR technologies

Promoting international collaboration for CDR assessment

Mission Innovation /CDR Mission

Mission Innovation is a global initiative catalysing an action and investment in research, development and towards the Paris Agreement goals and pathways to net zero.

CARBON DIOXIDE REMOVAL

Source: Mission Innovation website (https://mission-innovation.net/)

- **Develop standard LCA (life cycle assessment) / TEA (techno-economic assessment) methods for DAC (direct air capture) and ERW (enhanced rock weathering) within the LCA/TEA technical track activities.**
- **LCA/TEA case studies (of DAC and ERW) for member countries to analyze the impacts of regional (climate, geological, and financial) conditions.**

Other Initiatives

- **Non-profit organization for voluntary credits: Cascade**
- **Collaboration with the US DOE （ARPA-E）**

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Our pursuit for MRV of CDR

CDR: Carbon Dioxide Removal

MRV: Measurement, Reporting and Verification

Relationship between atmospheric CO_2 and O_2 variations

- Fossil fuel combustion and biospheric processes cause fluctuations in both CO_2 and O_2.
- CDRs, such as DAC and weathering, lower CO_2 levels without affecting O_2 levels.

- Simultaneous observations of CO_2 and O_2 are valuable for evaluating the CO_2 cycle.

Gas fuels $CH_4 + 2O_2\downarrow \rightarrow CO_2\uparrow + 2H_2O$

Liquid fuels $C_8H_{18} + 12.5O_2\downarrow \rightarrow 8CO_2\uparrow + 9H_2O$

Solid fuels $C + O_2\downarrow \rightarrow CO_2\uparrow$

$\Delta O_2 \geqq \Delta CO_2$

Photosynthesis $6CO_2\downarrow + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2\uparrow$

Respiration $C_6H_{12}O_6 + 6O_2\downarrow + 6H_2O \rightarrow 6CO_2\uparrow + 12H_2O$

$\Delta O_2 = \Delta CO_2$

DAC $CO_2\downarrow + 2KOH \rightarrow K_2CO_3 + H_2O$

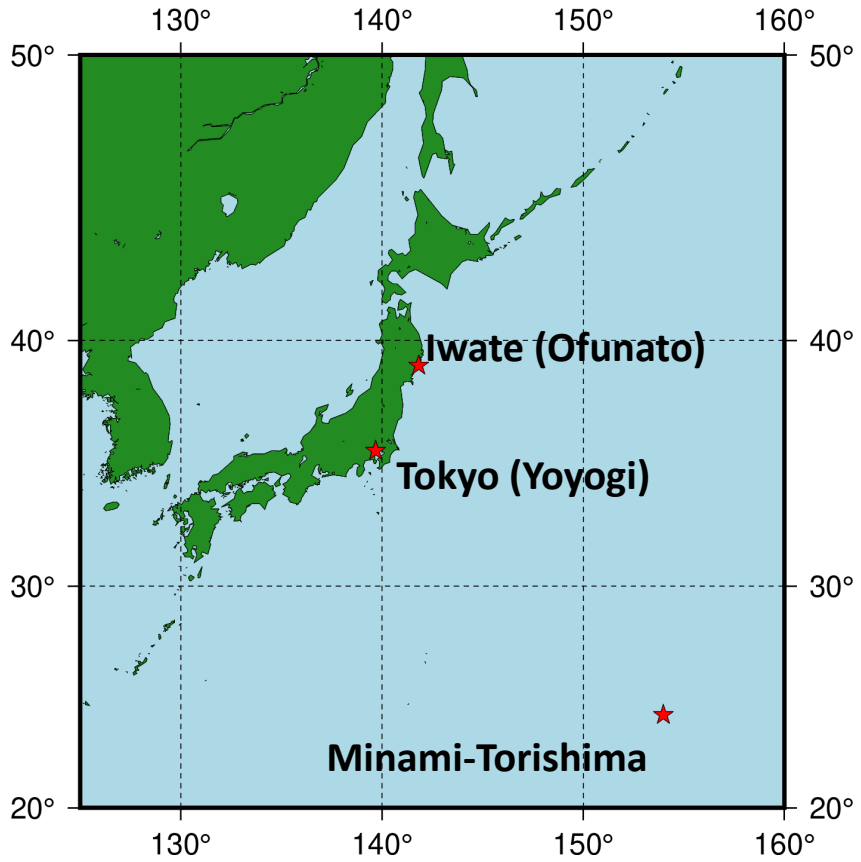
Weathering $CaMgSi_2O_6 + 4CO_2\downarrow + 6H_2O \rightarrow Mg^{2+} + Ca^{2+} + 2H_4SiO_4 + 4HCO_3^-$

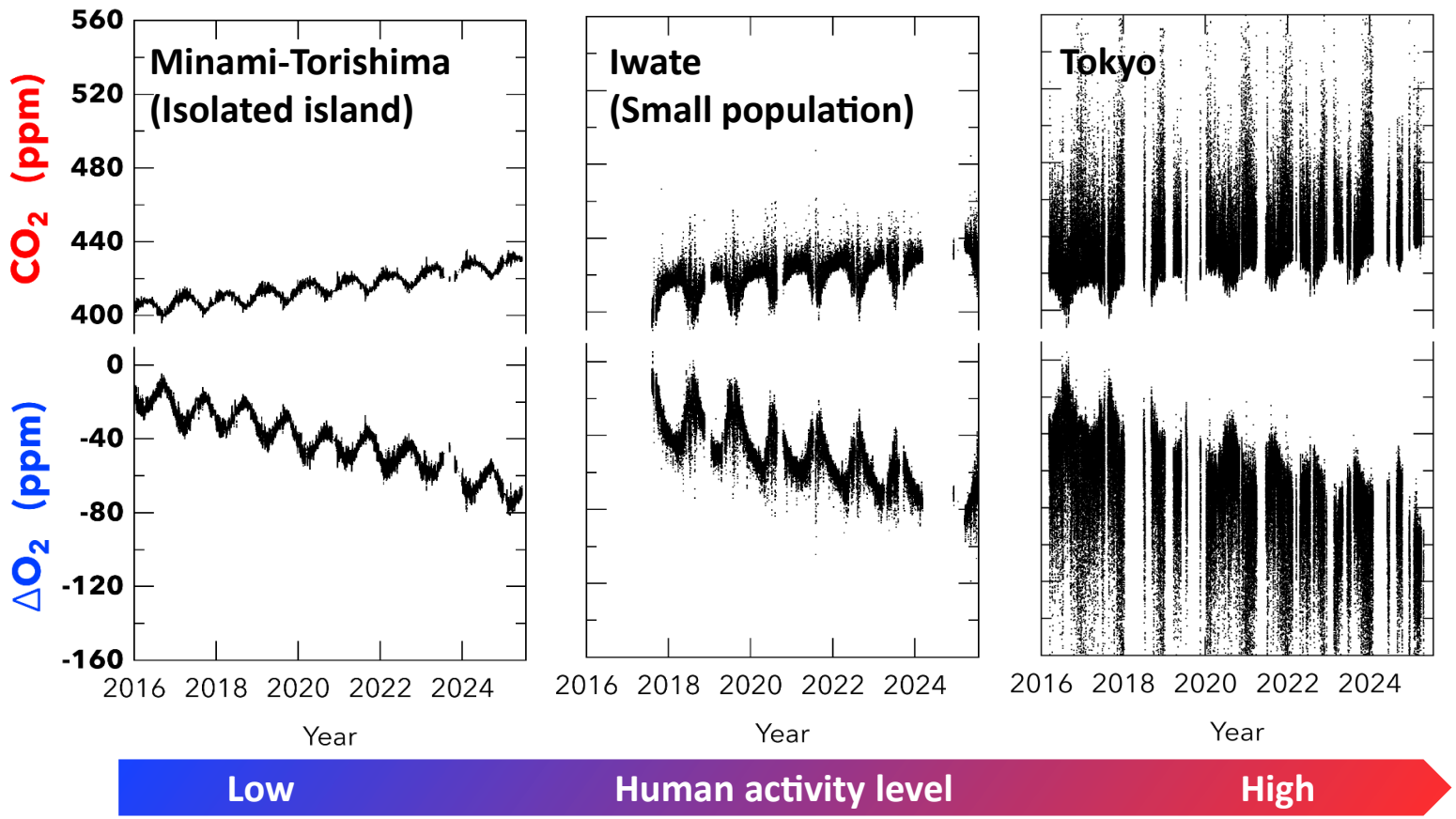
Ocean $H_2O + CO_2\downarrow + CO_3^{2-} \rightarrow 2HCO_3^-$

ΔCO_2

Simultaneous observations of atmospheric CO_2 and O_2

- AIST developed an ultra-high-precision measurement system for atmospheric O_2 and integrated it with the observation of atmospheric CO_2.
- The observation data clearly demonstrate that the CO_2 level rises due to human activities, whereas the O_2 level decreases.





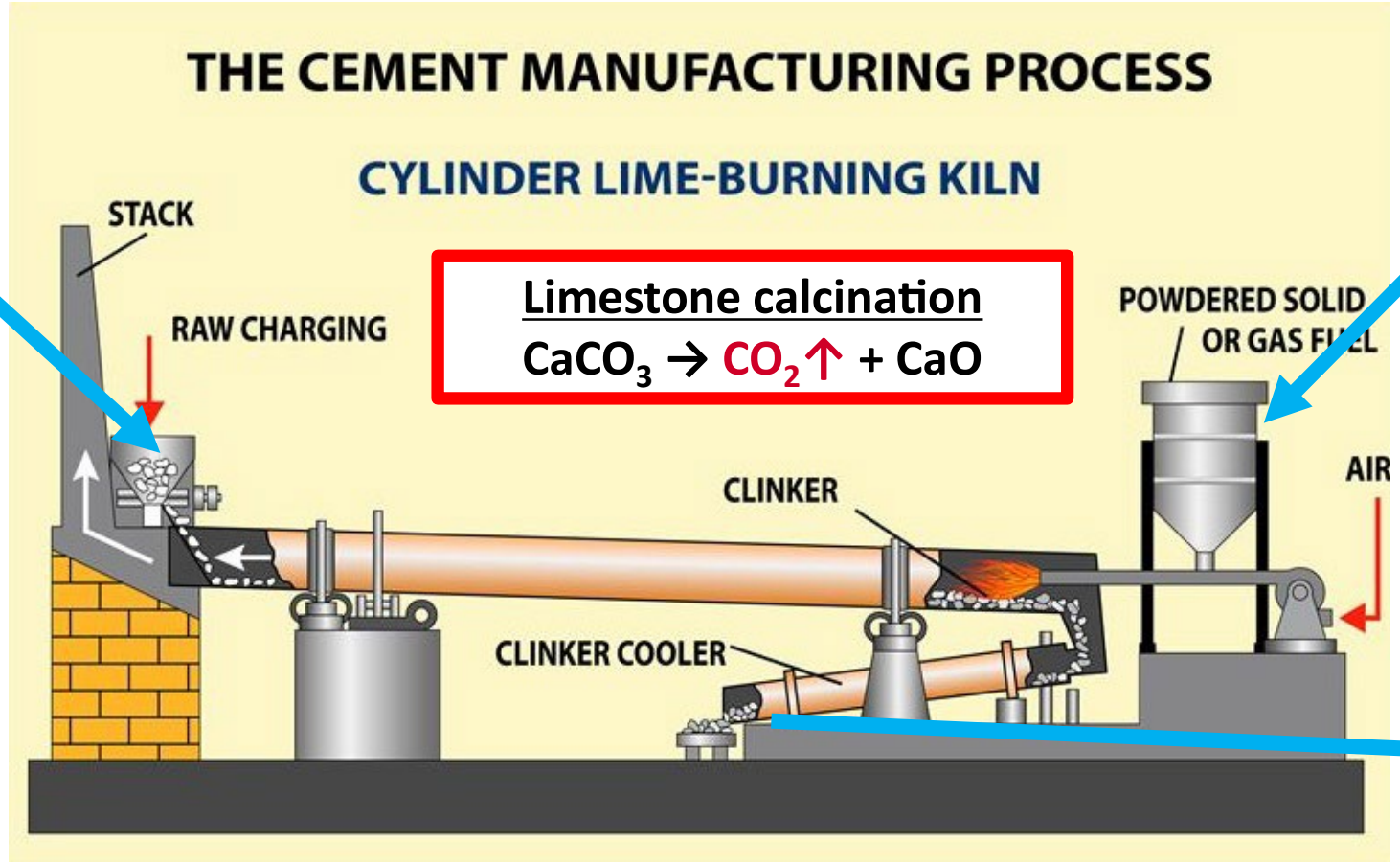
Sources: Updated from Ishidoya et al. (2017). SOLA, 13, doi:10.2151/sola.2017-042, Ishidoya et al. (2020). Atmos. Chem. Phys., 20, https://doi.org/10.5194/acp-20-5293-2020, and Ishidoya et al. (2024). Atmos. Chem. Phys., 24, https://doi.org/10.5194/acp-24-1059-2024.

CO_2 emissions from cement production

- Cement production emits CO_2 from the limestone calcination and the burning of fossil fuels.
- Limestone calcination releases CO_2 without O_2 decrease.
- **We attempted to determine whether CO_2 emissions by calcination could be detected from the atmospheric observation data.**

Raw material

Limestone



Heat source

Solid fuel

$C + O_2\downarrow \rightarrow CO_2\uparrow$

Gas fuel

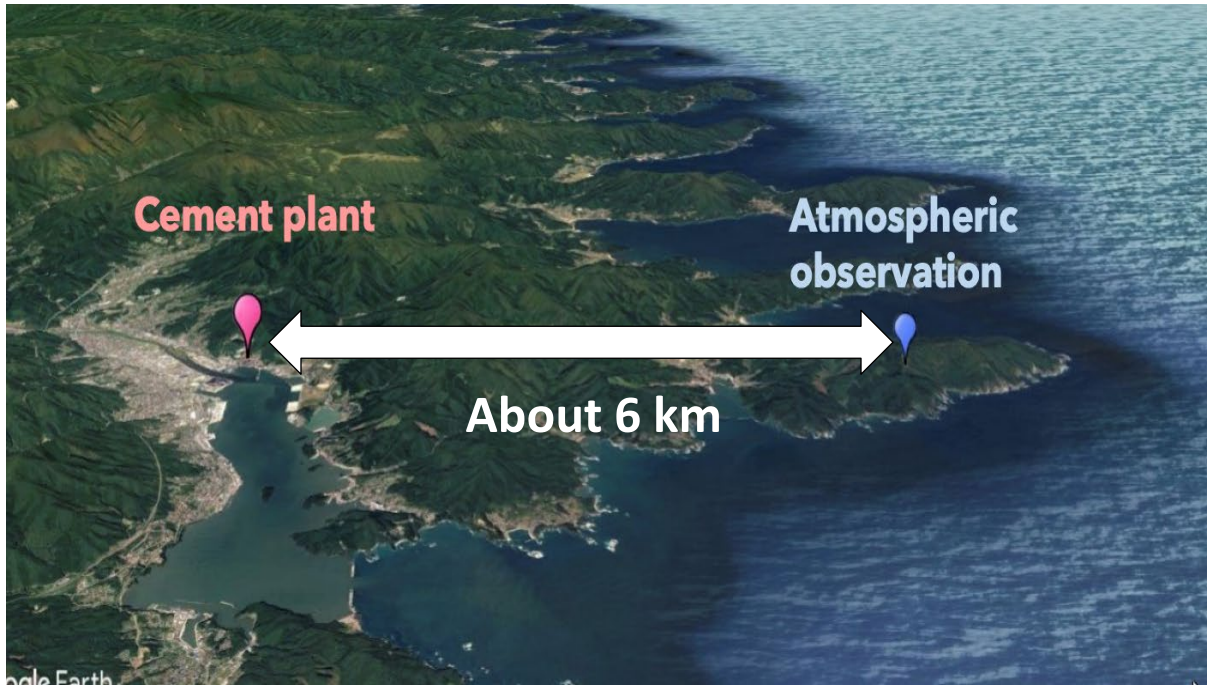
$CH_4 + 2O_2\downarrow \rightarrow CO_2\uparrow + 2H_2O$

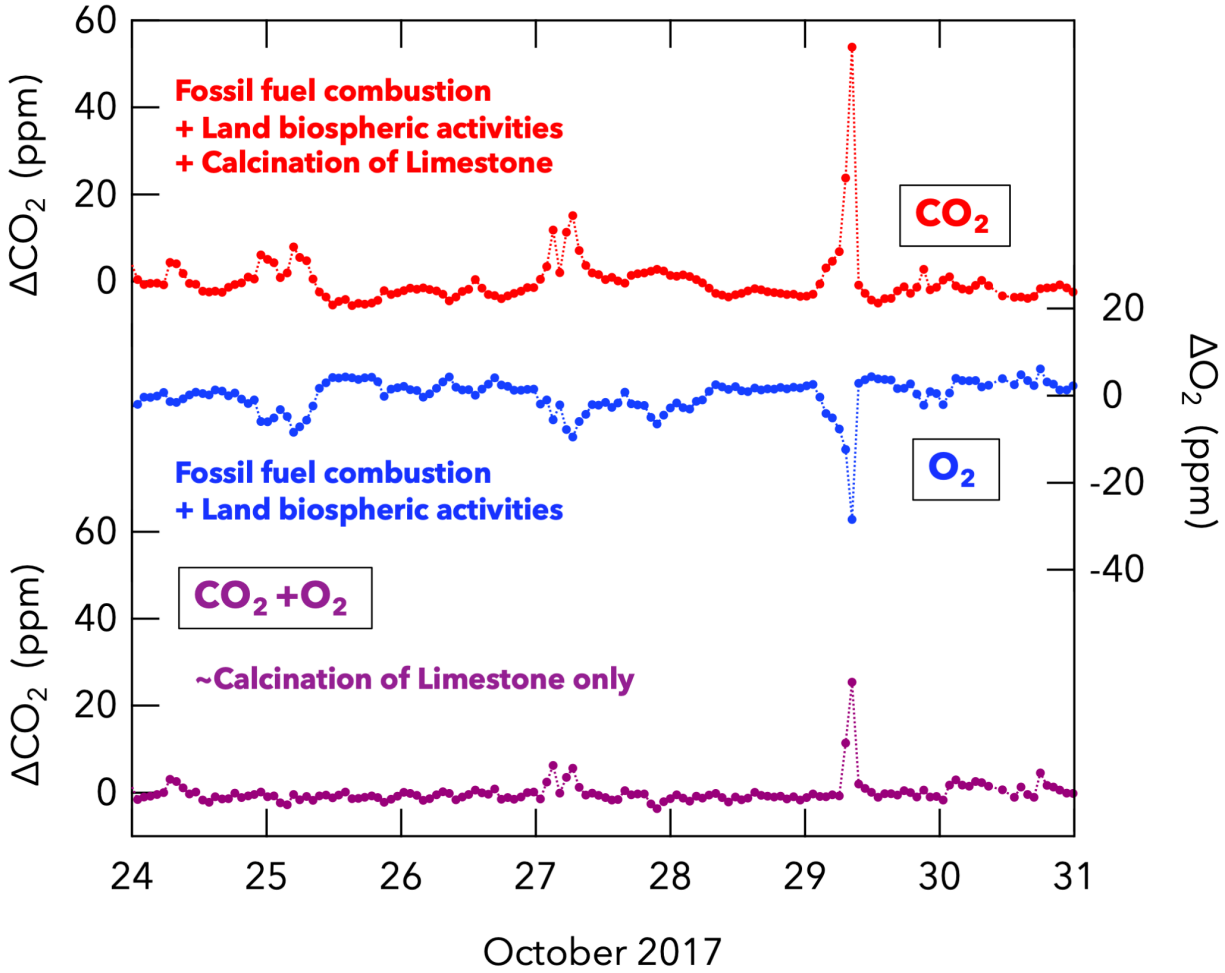
Product

Cement

Atmospheric CO_2 signals due to limestone calcination

- CO_2 emissions from calcination were effectively identified using a combined indicator of CO_2 and O_2 measured near a cement plant.
- This method can also be applied to detect CO_2 absorption by CDR technologies such as DAC.





Source: Ishidoya et al. (2024). Atmos. Chem. Phys., 24, https://doi.org/10.5194/acp-24-1059-2024.

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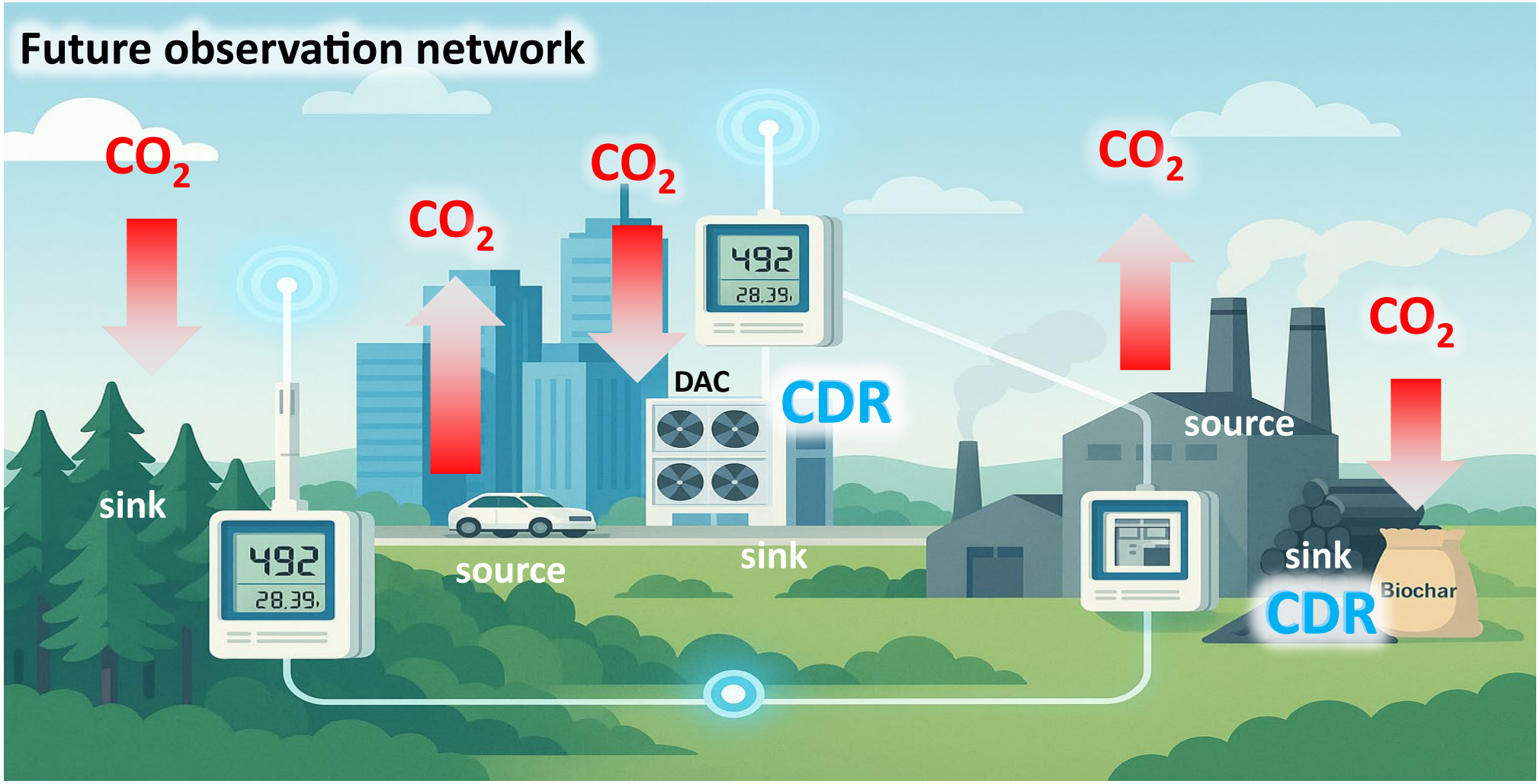
Our future vision and summary

Future vision for MRV targeting CDR

- Establishing an observation network of CO_2 and O_2 is valuable for the MRV of CDRs.
- AIST started research using CO_2 sensors to expand the observation network of CO_2 and O_2.



Observation networks using

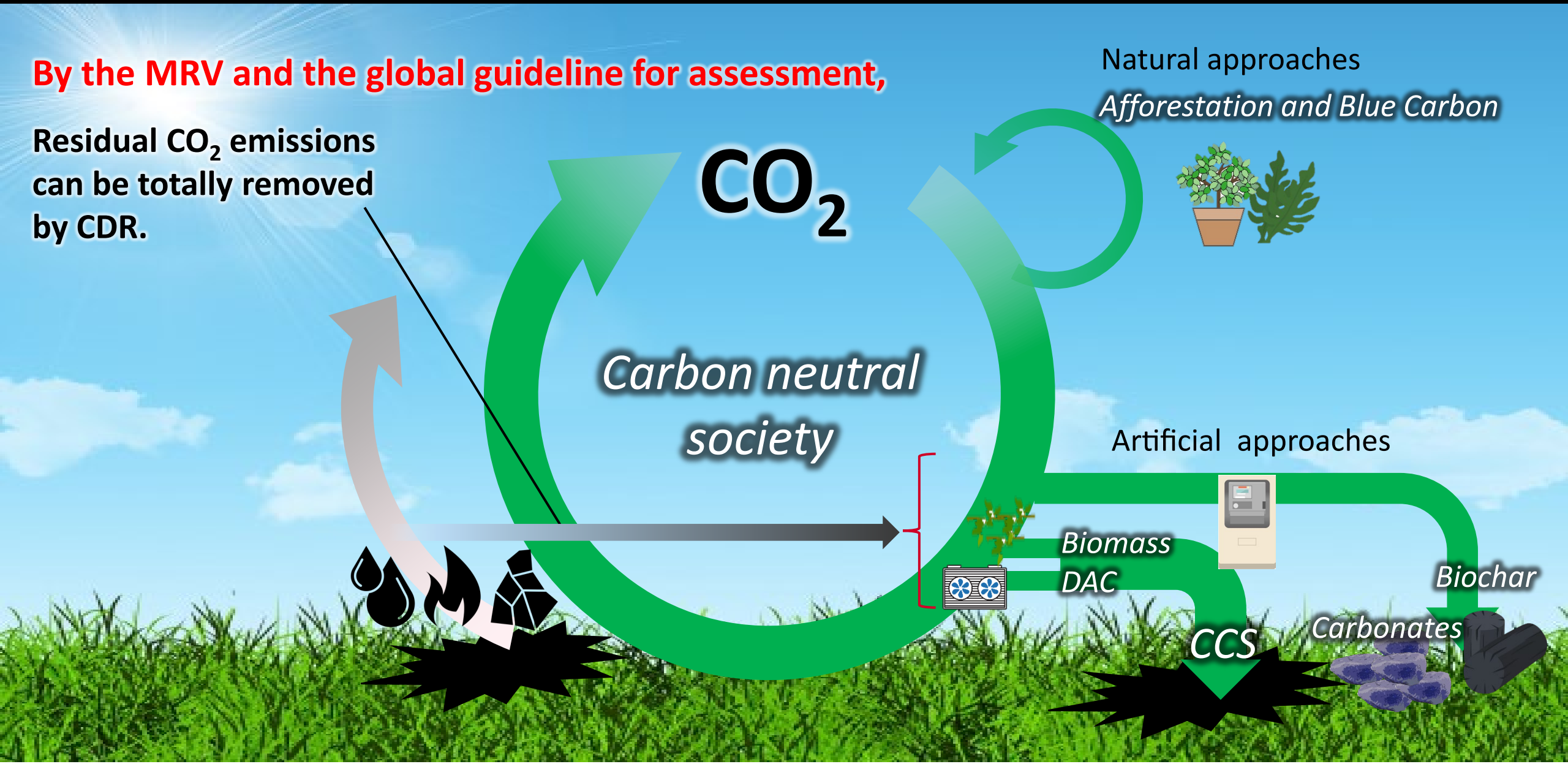
- Low cost
- High reliability

CO_2/O_2 sensors

Summary

By the MRV and the global guideline for assessment,

Residual CO_2 emissions can be totally removed by CDR.



Thank you very much for your kind attention!

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