Breakout Group 2

Inorganic processes and storage: rock weathering, ocean alkalinisation, concrete carbonation

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ipcc
INTERGOVERNMENTAL PANEL ON climate change

WMO
UN environment programme

Overview

- Inorganic processes and storage: concrete carbonation

rock weathering, ocean alkalinization

- In some cases capture and storage activity are the same (e.g. weathering on croplands) and in some cases capture occurs, then storage (e.g. CO_2 removal from oceans)

- Level of maturity of processes varies widely:
  - Experience on carbonation > rock weathering and oceans

General Considerations: All

- Recognized activities that collectively offer significant removals/reductions in mitigation scenarios
- They would benefit from international guidelines for MRV
- Methods for CDR should be comparable and as rigorous as methods for capture
- Q1. **Assessment Criteria:** Suggested evaluation criteria are valid; also considered what is scope of report/technology, “anthropogenic” versus “natural”, and whether annual removals/reductions could be assessed
- Q2. **Completeness:** We started with three primary activities for consideration:
  - Concrete carbonation
  - Enhanced weathering
  - Ocean alkalinity enhancement

→ Discussions resulted in 9 activities to be considered in a future methodological report (Table 1).

Table 1: CDR pathways inorganic processes and storage

Group	Activities discussed
Carbon capture in products	• **Concrete carbonation** (incl. enhanced concrete carbonation) • Carbonatable by-product materials (where not included elsewhere in national GHG inventory, e.g. slags, precipitated calcium carbonate)
Anthropogenic mineral processes with storage of carbon in minerals or as bicarbonate ions	• **Enhanced weathering** on managed land • Enhanced weathering in rivers • Ex-situ mineralization (open and closed systems) including enhanced weathering using biogenic CO_2 (wastewater alkalinity dosing) • In-situ mineralization (sub-surface injection and rapid mineralization) • **Ocean alkalinity enhancement** (mineral based and electrochemical) • Direct ocean CO_2 removal (stripping CO_2 from seawater)

These were considered significantly different to warrant consideration

Concrete carbonation

- **Scope:** Concrete carbonation could include enhanced carbonation

Is activity worth considering further?	Y
Are there gaps in existing methods?	Y
Can you delineate anthropogenic and natural?	Y (all anthropogenic)
Can you generate annual estimates?	Y
Can you estimate within national borders?	Y

- **Relevant history:**
  - Proposed for inclusion in 2019 Refinement, but too late in the process for full consideration.
  - Papers submitted to EFDB, but further revision was required (e.g. reflect historical use of concrete and annual emissions).
  - View of the group: Methodological issues could be addressed.

Concrete carbonation

Question 3 on Taxonomy

- Elements of technology chain are known; consider if clinker production in one country (emissions), and cement production and use in another country (uptake).
- Ensure that any methods reflect annual uptake
- If reported, is it reported in 2.H (Other) (consistent with text in 2006 IPCC Guidelines) or in 2.A (consistent with footnote 5 on "other reductions" in IPCC reporting tables).
    - 2.A. Is called "Cement Production" – if carbon capture in products consided here, would name of category change?

Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies

- Method for uptake not in Guidelines
- Possible options:
    - Amendment to existing equation to add uptake (could have negative emissions if uptake in current year greater than emissions)
    - Add CO_2 uptake separately
    - Adjust CO_2 EF for clinker to reflect year 1 uptake (category name would have to change)

Concrete carbonation

Question 5 – Feasibility of Tier 1 methods

- Literature robust and growing; sufficient available evidence.
- Documented methods have been suggested (Sweden, UK). Methods may assume stable cement use; need to look where growth is.
- Can estimate year-by-year absorption applying an average carbonation rate to a type of concrete (know fraction of structural versus non-structural).
    - National level activity data for cement exists in most countries.

Concrete carbonation

Question 6 – Higher tier methods

-Available in literature; we know factors leading to uptake.

-Analogues: waste model, HWP, F-gases, abandoned coal mines

Question 7 – Verification Activities

- If there are multiple tiers, can use alternative tiers.
- As we know factors that influence emissions, verification is possible

Other Carbonatable Materials

- Carbonatable materials can be used as inputs to products, storage medium, or feedstock to processes discussed (e.g. Fly ash, slags, PCC)
- Overlap with storage of carbon in minerals, particularly ex situ mineralization
- Not further discussed

Enhanced Weathering

- Approaches to quantifying anthropogenic removals from enhanced weathering are relatively immature
- Efficiency of carbon removal dependent on process specific information (e.g. mineralogy)
- Terminology needs to be refined

Scope suggested for further consideration:

Anthropogenic mineral processes with storage of inorganic carbon in minerals or as bicarbonate ions.

- Enhanced weathering on managed land *(more advanced)*
- Ex-situ mineralization (open and closed systems) including enhanced weathering using biogenic CO_2 (wastewater alkalinity dosing) *(closed systems including wastewater more advanced)*
- Enhanced weathering in rivers
- In-situ mineralization (sub-surface injection and rapid mineralization) *(important, but is this the correct place)*

- Valid to consider all activities; focused mostly on EW on managed land

Enhanced Weathering

Is activity worth considering further?	Y
Are there gaps in existing methods?	Y
Can you delineate anthropogenic and natural?	Process: Y CO_2 uptake: ? (questions of baseline)
Can you generate annual estimates?	Probably
Can we estimate within national borders?	Where does uptake and reversal occur? Land-based- Probably Other - Y

Reminder: Definition of national boundary: National inventories include GHG emissions and removals taking place within national territory and **offshore areas over which the country has jurisdiction.**

May need to consider definition of national boundary: 2006 GL have unique definitions for navigation/aviation and transport

Enhanced Weathering

Question 3 on Taxonomy:

- Enhanced weathering on Managed Land:
  - Single category, if so where, OR updating EFs throughout GL to take account of EW practices (e.g. rice, croplands, wastewater treatment).
  - Boundary question: how do you separate EW and ocean alkalinity, as the ocean may ultimately be the fate.
  - Overlap with soil organic carbon ; emissions of other GHGs (CH_4 and N_2O)
- Other EW:
  - Single category, if so where, OR updating EFs throughout GL to take account of EW practices (e.g. energy (CCS), IPPU (chemical industry), wastewater)

Enhanced Weathering

Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies

- Method for EW not in Guidelines, but do have
  - CO_2 emissions from liming of soils;
  - Organic stocks from mineral soils
- Regarding dissolved inorganic carbon (DIC)- there are pools in soil, rivers and ocean. To understand the weathering you need to understand the impact on DIC. There is discussion on DIC in appendix to Wetlands Supplement.

Question 5 -7 – Feasibility of methods

- Limited data for all EW approaches, but growing rapidly.
- Tier 3 methods considered, insufficient information to develop Tier 1/ 2.

Enhanced Weathering

Activity	Factors that may need to be considered in a higher tier method (list not complete)
Enhanced weathering on managed land	Rocks react at different rates, impact water chemistry, soil storage. Because it impacts soil storage and biomass, relationship with other AFOLU pools needs to be considered Monitoring: How do we consider here organic carbon. Interaction with SOC, carbonate precipitation, rate of mineral weathering, secondary mineral formation (carbonate, clay formation), non-carbonic acid neutralization, methane and N_2O emissions, mineral composition, mineral type, diameter and quantity. Soil type, soil moisture, crop type…
Enhanced weathering in rivers	Dissolution kinetics, secondary precipitation, interactions with ecosystems, interaction with DIC
Ex-situ mineralization (open versus closed systems) including enhanced weathering using biogenic CO_2 (wastewater alkalinity dosing)	Potential depends on the removal potential per ton of processed mineral and annual total production of mineral, CO_2 uptake rate
In-situ mineralization	Boundaries of in-situ and ex-situ mineralization

Verification: Limited field data available to assess removal efficiency. Signal-to-noise problem common across open system pathways. Reviewing paper from Cascade about EW on managed lands.

Ocean-based Activities

Scope

- Ocean alkalinity enhancement : Mineral-based and electrochemical acid removal
- Direct ocean CO_2 removal: Stripping CO_2 from seawater
- Would need to consider possible emissions/reversals related to the ocean-based activities
- How does IPCC definition of national boundary apply to Oceans? *National inventories include GHG emissions and removals taking place within national territory and* ***offshore areas over which the country has jurisdiction.***

Is activity worth considering further?	Y (listed ones)
Are there gaps in existing methods?	Y
Can you delineate anthropogenic and natural?	Process: Y CO_2 uptake: ?
Can you generate annual estimates?	Probably
Can you estimate within national borders?	Unknown

Ocean-based Activities

Question 3 on Taxonomy

- Single category, if so where, OR include throughout GL (e.g. “Other”, separate CDR category, IPPU (chemical industry or other))

- Technology chain of removals and emissions; all steps required for a net removal :
  - Adding alkalinity / remove CO_2
  - Sequester CO_2 / neutralize or sequester acid
  - Enhanced ocean uptake

- But consider –
  - How to handle oceans in national GHG Inventory (beyond Wetlands Supplement?)
  - Relationship with London Protocol, CBD, IMO

Ocean-based Activities

Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies

- No existing methods
- Who is responsible for monitoring and verification of reversals. Consider international law

Question 5 – Feasibility of Tier 1 methods

Not applicable

Ocean-based Activities

Question 6 – Higher tier methods

- Tier 3 method may be possible

Question 7 – Verification Activities

- Requires secure storage of the CO_2 (direct ocean removal), acid (electrochemical OAE), to avoid reversal
- Not possible to do measurement based verification; challenging to monitoring uptake in temporally and spatially and delineation of anthropogenic/natural) ; difficult to assess signal to noise
- Ocean alkalinity and CO_2 removal: both have air sea exchange. Facility level data required. But for mineral based, there may be additional elements that come in. This latter will require more experiments.

Ocean-based Activities

Activity	Factors that may need to be considered in a higher tier method
Ocean alkalinity enhancement : Mineral based and electrochemical	Measurement perturbation, how much CO_2 removed, how much alkalinity added (quantity, when and where), chemical distribution, biochemical behavior, mineralogy, biological impact, etc.
Direct ocean CO_2 removal: Stripping CO_2 from seawater	CO_2 removed (quantity, when and where), tracking CO_2 extraction, transport, storage.

THANK YOU

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