Urban CDR Pathway Fact Sheet

Mineralizing CO_2 for building materials

LEGEND

Application: Atmospheric or biogenic CO_2* mineralized into solid carbonates (ex situ) that are used in building materials.

Permanence:

- Conversion of such CO_2 into rock is effectively a permanent carbon removal, on a 10,000+ year time scale. Only exposure to acid or prolonged, extreme heat (over 500°C) could release the CO_2 back into the air.

Infrastructure: Sourcing atmospheric or biogenic CO_2; Specialized conditioning facilities; Compression and purification units; CO_2 transportation assets; CO_2 injection systems; Carbonation curing chambers; Concrete mixing and forming equipment; Digital Monitoring, Reporting and Verification software.

Guidance: Identify the relevant pathway steps, inputs, and outputs. Calculate the carbon sequestration impact. Report emissions impacts in the city's emissions inventory in accordance with the GHG Protocol for Cities.

Carbon mineralization to concrete for permanent storage can be done with all sources of CO_2. Only CO_2 captured from the atmosphere or biogenic emissions can lead to carbon removal.

PATHWAY

In this pathway, atmospheric or biogenic CO_2 is captured and chemically converted into carbonate minerals for use in building materials, such as aggregate, concrete, or a Supplementary Cementitious Material (SCM). CO_2 could be captured at a plant and transported, or captured from the atmosphere directly into the material input, including from indoor air. Concrete, a CO_2 sink readily manufactured in urban settings, constitutes a sizable and distributed sink capable of storing large quantities of CO_2.

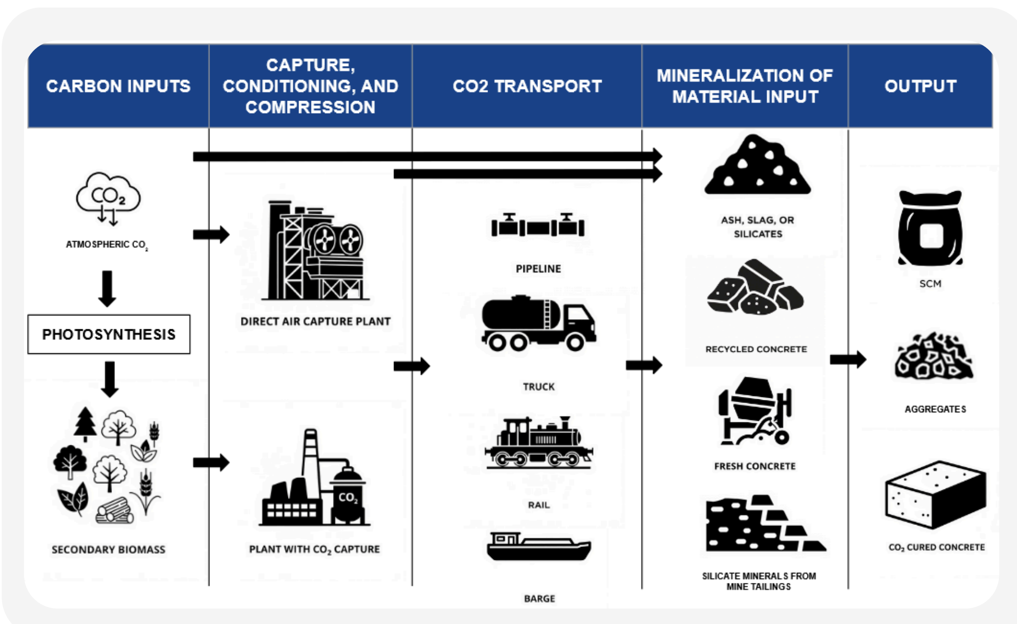

Figure 1: *Simplified pathway overview*

Several processes allow CO_2 to be removed through mineralization. These processes require infrastructure that enables the following steps.

CO_2 Sourcing:

- From air: CO_2 removed from air by materials that react with or absorb the CO_2 (direct air capture) or materials input that mineralize the CO_2 directly.
- From industrial point sources: byproduct or waste CO_2 contained in biogenic flue gas streams. The biogenic CO_2 may be in a waste stream that also contains CO_2 from fossil fuel combustion. Potential sources include:
  - Fermentation processes, such as breweries and ethanol plants;
  - Municipal solid waste (MSW) incinerators;
  - Cement kilns burning biofuel;
  - Biomethane plants, biodigesters, and sewage treatment plants; and
  - Landfills.

CO_2 Conditioning:

- In some cases, the captured CO_2 needs to be conditioned to meet the requirements of downstream processes. This entails removing impurities and moisture.
- Compression may be necessary for CO_2 transport.

CO_2 Transport:

- If CO_2 capture and mineralization are not co-located, the conditioned CO_2 is transported to a facility where the mineralization takes place.

CO_2 Mineralization:

- The CO_2 is mineralized into carbonates during the concrete curing process, which are incorporated into building materials.
- CO_2 mineralization requires materials, chemicals, and energy. Some mineralization processes react CO_2 with waste materials (such as slag from iron and steel plants, landfilled coal plant fly ash, municipal solid waste incinerator ash, and recycled concrete) which are then used to produce a final building material such as concrete.

ACCOUNTING

Emission risks: The steps described above require energy and produce CO_2 emissions that must be accounted for. Producing the chemicals used to capture and process the CO_2 results in emissions. Some of the sourced CO_2 may be from fossil fuel combustion, thus counting as avoidance rather than removal. Mineralizing waste material may also reduce that waste's availability for other purposes, increasing emissions for those processes (see "leakage" below). Moreover, certain mineralization techniques may inhibit mineralization that otherwise may have occurred naturally. Finally, the use of carbon negative materials prevents the use of CO_2 intensive cement, leading to emissions avoidance. These factors may be material and need to be accounted for to establish the net amount of CO_2 removal that can be claimed. The claimed amount must be additional to what would have occurred otherwise.

Emissions impacts to account for:

- Energy used to capture, condition, transport, and mineralize the CO_2.
- Energy use in the production and transport of the chemicals and materials needed for the mineralization processes.
- Carbon leakage associated with reduced supply or increased prices of materials used as inputs, if other manufacturing processes then switch to using materials with a higher carbon footprint.
- Reductions in the capacity of the construction materials to naturally mineralize CO_2 from the air over time.

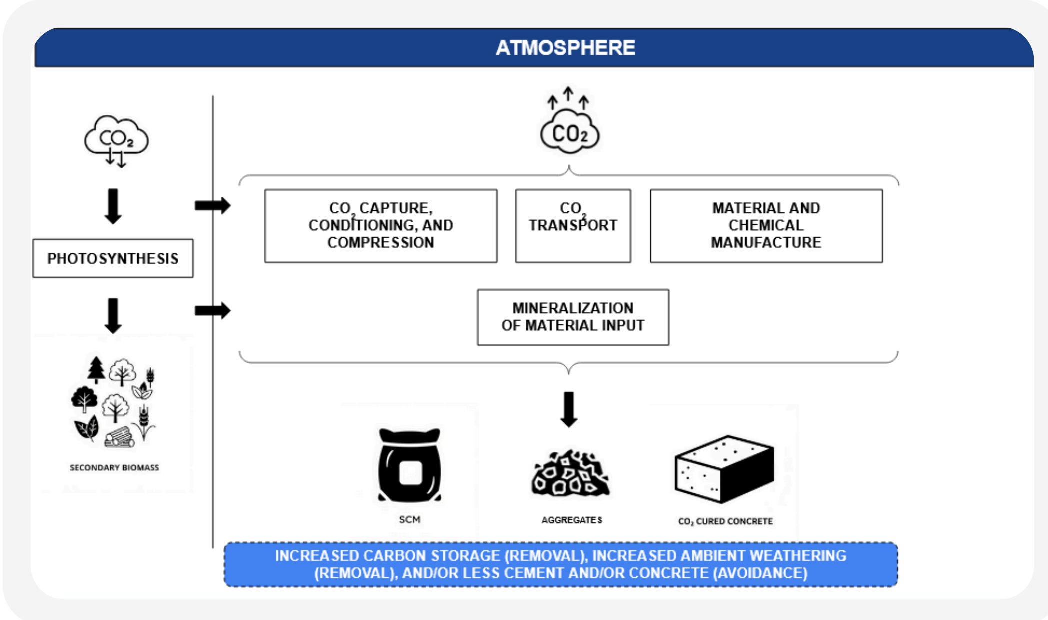

Figure 2: *Simplified carbon flow diagram*

Mitigation Strategies:

- [ ] Minimize transport distances by building close to materials feedstock;
- [ ] Minimize transport distances by building close to the CO_2 sources;
- [ ] Prioritize CO_2 and waste material sources without or with limited competing uses;
- [ ] Use highly efficient system designs allowing for energy recovery;
- [ ] Switch to electric/biofuel/hydrogen logistics; and
- [ ] Power with renewables, track carbon intensity.

Accounting protocols:

Gold Standard - Carbon Mineralisation Using Reactive Mineral Waste, v2.0, Isometric Protocol - CO_2 Storage via Carbonation in the Built Environment, v1.0, Isometric Protocol - Open System Ex-Situ Mineralization (for mining industry), Puro Standard - Carbonated Materials Methodology for CO_2 Removal, Verra Verified Carbon Standard - VM0043 CO_2 Utilization in Concrete Production, v1.1

The urban CDR value chain illustrated in this fact sheet is a reference design based on common infrastructure types and waste streams. However, urban systems differ widely in their spatial form, governance, population density, and resource flows. This model should be interpreted as adaptable.

Possible variations:

- **Centralized vs. Decentralized vs. Hybrid Mineralization Systems:** Some cities may favor approaches that involve capturing CO_2 from large point sources, such as power plants and industrial facilities, and transporting it to dedicated mineralization facilities. Others may opt for capturing and utilizing CO_2 at smaller, distributed locations, such as individual concrete plants or construction and demolition sites, leveraging the readily available waste materials. Hybrid approaches allow for optimal combinations, such as capturing CO_2 from large sources and transporting it to regional hubs for distribution and utilization at local concrete plants. Identifying the most appropriate approach requires context-specific decision making

OPPORTUNITIES AND GAPS

Acceleration:

- **Value Chain Upgrade:** Key value chain elements to remove CO_2 can be leveraged to enable materials and end products to be manufactured utilizing CO_2.
- **CDR-Ready City Planning:** Urban zoning for CO_2 transportation infrastructure can aggregate biogenic CO_2 and industrial gases that are already available in urban areas.
- **Carbon Market Entry Point:** Verified carbon negative materials in construction qualify for voluntary carbon credits, helping de-risk project finance.

Gaps:

- **Carbon Accounting Uncertainty:** Holistic MRV protocols are needed to account for a reduction of natural mineralization capacity of the materials.
- **MRV Complexity vs Capacity:** Carbon accounting protocols are technically rigorous, but many municipalities and local labs are under-resourced.
- **Regulatory Incompatibility:** Urban building codes, procurement policies, waste and end-of-life regulations rarely permit circular material use.
- **Sustaining Carbon Integrity:** Long-term storage and leakage risks must be verified consistently, with emphasis on emissions removal.
- **Infrastructure Deficit:** Cities may lack CO_2 sourcing infrastructure and the equipment needed to enable the CO_2 to be mineralized.

CORE RECOMMENDATIONS

- **Adjust public procurement criteria and tender processes to benefit projects that use sustainable construction materials with a lower carbon footprint.**
- **Map available sources of biogenic CO_2 in relation to concrete production and use locations and volumes, and identify available infrastructure and future needs.**
- **Map options to integrate fossil CO_2 captured directly from the kiln flue gas and using the hub and spoke supply chain of cement to concrete to construction.**
- **Evaluate availability and management requirements of waste materials, such as logistics, preexisting uses, and departmental needs, and overlay this with CO_2 source and product use mapping to identify 'mineralization corridors'**
- **Establish a dedicated collaboration platform to matchmake CO_2 suppliers, waste material processors, construction product manufacturers, and project developers.**

INNOVATION LANDSCAPE

Building materials industries, particularly concrete, operate on thin profit margins and require safe, durable products. Much of today's innovation focuses on reducing costs and long-term evaluation of small-scale projects, with an eye toward achieving cost parity and scaling up.

LEADING CITIES

- **Baltimore, Maryland, US** - CO_2 from indoor air mineralized into limestone
- **Belgrade, Maine, US** - atmospheric CO_2 mineralized in slag used in cement-free pavers
- **Berlin, Germany** - industrial CO_2 mineralized in carbon-negative cement substitute (emissions reduction)
- **Brisbane, California, US** - atmospheric CO_2 mineralized in concrete
- **Durham, North Carolina, US** - industrial CO_2 mineralized in sidewalks
- **Four Corners, US** - Carbon Removal + Concrete campaign
- **Hauts-de-France, France** - atmospheric CO_2 mineralized in slag in cement-free concrete blocks
- **Holland Landing, Ontario, Canada** - atmospheric CO_2 mineralized in slag in cement-free concrete blocks
- **Madison, Wisconsin, US** - Girl Scouts convince city to use low-carbon concrete in infrastructure projects
- **Mississauga, Ontario, Canada** - industrial CO2 mineralized in carbon-negative cement substitute (emissions reduction)
- **Milan, Italy** - biogenic CO_2 mineralized in concrete plant residual water
- **Newark, New Jersey, US** - CO_2 from airport indoor air mineralized for on-site use in concrete
- **Port Authority of New York and New Jersey, US** - Clean Construction Program
- **Port of Rotterdam, Netherlands** - atmospheric CO_2 mineralized in olivine to make cement substitute
- **Zurich, Switzerland** - biogenic CO_2 mineralised in recycled concrete

Acknowledgment: *This fact sheet is part of a series. The development of the fact sheet was led by Francisco Koch and Sue Dorward, and received input from partners, cities, and developers associated with the Initiative. The following individuals in particular contributed, either in their organizational or personal capacity: Grant Faber, Aidan Preston, Simone Mangili (CNCA), Lucia Dora Simonelli (CRSI), Kyle Clark Sutton (RMI), Dylan Marks (South Pole), Pol Knops (Paebbl), Julia Hestenes (Thalo Labs), Yuri Mytko (CarbiCrete), and Madison Savilow (Carbon Upcycling Technologies).*