

METHODOLOGY

CARBON MINERALISATION USING REACTIVE MINERAL WASTE

SUSTAINABLE DEVELOPMENT GOAL 13

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SUMMARY

This methodology applies to activities which store biogenic or atmospheric carbon dioxide (CO₂) in the form of stable carbonate minerals [e.g, (x,Ca,Mg,Fe)CO₃] via the carbonation of mineral waste streams. Carbonation is a natural process which is observed during weathering (e.g., in concrete structures, where CO₂ reacts with the cement phase of concrete). Similar to the natural process, carbonation can be induced in an industrial setting by exposing reactive materials to increased concentrations of CO₂. The stable carbonate minerals which form as a result can durably store carbon for millennia (1,000+ years).

This methodology provides three different processes which use either direct (solid or aqueous/slurry state) or indirect mineral carbonation. Direct processes imitate the natural process of weathering, but they increase the reaction rate through different factors such as an increased CO_2 concentration or increased contact surface between the CO_2 and reactive mineral waste. Indirect mineral carbonation processes use solvents to extract alkalis from the mineral waste (e.g., calcium oxide [CaO], magnesium oxide [MgO]) which are then exposed to elevated CO_2 concentrations. As a result, carbonate minerals form and precipitate from the solvent. Both methods can facilitate CO_2 removal through the durable storage of CO_2 in stable carbonate minerals. The carbonate minerals can be used as raw materials (e.g., for the construction industry), or they can be stored safely.

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1| KEY INFORMATION

1.1.1 | The following table describes the key information for the application of the methodology.

Table	1.	Kev	Information
IUDIC	- C.	ILC y	Inormation

Mitigation type	\Box Emission reduction $igtimes$ Emission removal
Typical mitigation activity (project) type*	An activity which involves the durable storage of atmospheric or biogenic CO_2 through the carbonation of reactive mineral waste, such as demolished concrete, concrete wastewater, incineration bottom ash, slags, and mine tailings via direct or indirect carbonation.
	* The terms "mitigation activity," "activity," and "project" refer to project activity and are used interchangeably.
Activity requirement	Engineered Carbon Dioxide Removals
Applicable Gold	\boxtimes Gold Standard Verified Emissions Reduction (GS-VER)
Standard for the Global Goals (GS4GG) products	Certified impact statement
Geographical applicability	Global
Applicable activity	ig Micro scale $ig $ Small scale $ig $ Large scale
(project) scale	A mitigation activity can claim emission reductions less than or equal to:
	- $10,000 \text{ tCO}_2$ eq per year for micro-scale activity
	- $60,000 \text{ tCO}_2 \text{ eq}$ per year for small-scale activity
Project activity start date	The earliest date on which the project developer has committed to expenditures related to the implementation of the mitigation activity.
Crediting period start date	The date of the start of operations (start of operation of first project of the bundle) or a maximum of two years prior to the date of project design certification, whichever occurs later.
Crediting period length	The crediting period ends with the technical life of the carbonation plant or a maximum of 45 years, whichever occurs earlier. The mitigation activity follows five-year renewal cycles per the latest version of GS4GG requirements for renewal of crediting period.

Limitations Th an re	he methodology shall be applied only to activities involving the torage of atmospheric and/or biogenic CO ₂ . Additional capture nd transport methodology modules shall be applied where elevant.
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2| **DEFINITIONS**

2.1.1 | The definitions outlined in the <u>GS4GG Glossary</u> and the Engineered Carbon Dioxide Removal Activity Requirements shall apply, in addition to those outlined in Table 2.

TERM	DEFINITION
Ash	A powdery or granular residue resulting from the incineration or combustion of organic or inorganic materials.
Biogenic carbon	Organic carbon incorporated into biological material such as plants, algae, and other microorganisms. Also referred to as "plant biomass" in some contexts.
Calcination	A highly endothermic process in which limestone is converted into CaO and CO_2 via thermal decomposition.
Carbonated concrete aggregate	Concrete aggregate that has undergone the carbonation process and has sequestered CO_2 in the form of stable carbonate mineral(s).
Carbonated mineral waste	Mineral waste that has undergone the carbonation process and has sequestered CO_2 in the form of stable carbonate mineral(s).
Carbonated product	Carbonated concrete aggregate and/or carbonated mineral waste and/or regenerated sand.
Carbonation (process)	A process in which CO_2 reacts with oxides, such as CaO or MgO, to form stable carbonate minerals. The carbonation reaction is exothermic. The carbonation of mineral waste can occur following contact between CO_2 and the feedstock material, which triggers a mineral reaction that is responsible for the formation of the carbonate (mineralisation).
Carbonation plant	An industrial facility where mineral waste is carbonated using a CO_2 -rich gas stream via direct or indirect processes. This typically occurs at a specific temperature and pressure and may utilise a solvent.
Cement	A substance used for construction which hardens and adheres to other materials to bind them together. Cement is typically a mixture of ground clinker and additives such as gypsum, silica fume, slag, limestone, and fly ash.
Clinker	A material which is ground with additives during the production of cement. To produce clinker, a homogeneous mixture of raw materials such as limestone, clay soil, and iron ore are ground and heated in a kiln to a sintering temperature of approximately 1450°C.

Table 2. Terms and Definitions

Concrete	A building material made from a mixture of gravel, sand, cement, and water.
Concrete aggregate	Demolition concrete crushed and sieved to form concrete aggregate with a certain grain size distribution (usually comprising particle sizes from 0 to 32 millimetres [mm]).
Demolition concrete	Includes all of the waste produced during the construction and demolition of buildings and infrastructure made from concrete.
Direct carbonation	A process involving the formation of carbonate minerals by direct exposure of reactive mineral waste feedstock to gaseous CO_2 . (See <u>Annex 1</u>)
Gravel	Coarse primary aggregates with a grain size bigger than 4 mm and smaller than 32 mm.
Indirect carbonation	A process involving the formation of carbonate minerals via a two-step chemical treatment of reactive mineral waste, including the dissolution of alkalis, followed by exposure to gaseous CO_2 . (See <u>Annex 1</u> .)
Materials Recovery Facility (MRF)	A facility where mineral waste is collected and processed for downstream uses or disposal, e.g., a recycling facility which separates demolished concrete or incinerated bottom ash components and typically processes it into concrete or road construction aggregate.
Mineralisation	Process in which elements or chemical compounds react to form a mineral. Carbonation is a type of mineralisation reaction.
(Reactive) Mineral waste	Byproducts or residual waste materials from established industrial activities such as construction, manufacturing, municipal waste treatment, biomass, or coal incineration. Reactive mineral wastes usually contain a high fraction of alkaline metal oxides in their compositions. Reactive mineral wastes include demolished concrete, slags, and ashes.
Regenerated sand	Sand that results from the indirect mineral carbonation of mineral waste. In the first step of the process, calcium is extracted from the mineral waste using an acidic solution, and the regenerated sand is filtered out.
Sand	Fine primary aggregates with a grain size smaller than 4 mm.
Slag	A byproduct of steel, iron, and aluminium manufacturing, formed during smelting and refining of metals (that contain reactive metal oxides such as CaO, MgO, and iron oxide [Fe ₂ O ₃]).
Slurry	A mixture of water and solids containing alkaline metal oxide elements, which is generated as a byproduct of or waste from industrial activities. Slurries may include concrete wastewater, gravel wastewater, and water with suspended slags or ashes.
Virgin concrete	Concrete with a recycled material content below 25% by weight.

3| SCOPE, APPLICABLITY, AND ENTRY INTO FORCE

3.1 | Scope

 3.1.1 | This methodology applies to activities which durably store biogenic or atmospheric CO₂ in the form of stable carbonate minerals [e.g., (x,Ca,Mg,Fe)CO₃] via the carbonation of mineral waste feedstock.

3.2 | Applicability

- 3.2.1 | The project activity shall use a mineral waste feedstock to sequester CO₂ before it enters a downstream process (e.g., as substitute for gravel, sand, or cement) or before it is landfilled.
- 3.2.2 | The carbonation process shall be direct or indirect. For further information regarding these processes, see <u>Annex 1</u>.

3.2.3 | **Carbonation facility:**

- a. The project shall be implemented at either a new or existing MRF, where mineral waste is generated, processed, or disposed.
- b. If the carbonation plant is located in the same facility as the source of CO_2 , the monitoring of the amount of total CO_2 consumption for carbonation shall be ensured (Parameter ID 13, as prescribed in <u>Section 7</u>).

3.2.4 | Source of CO₂ :

- a. The source of carbon shall be atmospheric or biogenic, in line with the Engineered Carbon Dioxide Removal Activity Requirements. The source of the CO_2 shall be documented and monitored as the parameter " CO_2 biogenic" (Parameter ID 18), as prescribed in <u>Section 7</u>.
- b. If the CO₂ is sourced from a new facility that did not exist in the baseline scenario, the project developer shall use a Gold Standard– approved methodology in addition to this methodology to ensure that all eligibility criteria and safeguards are met and that all emissions are accounted for.
- c. If the source of CO₂ is part of any other carbon programme or project, the project developer shall demonstrate in line with Gold Standard <u>Principles & Requirements</u> that no double-counting takes place.
- d. Project activities that involve the use of non-atmospheric or nonbiogenic sources of CO₂ may be considered for Gold Standard certification; however, these would be considered under carbon capture and storage or utilisation and would not be considered CO₂ removal projects, as per the Engineered Carbon Dioxide Removals Activity Requirements. The project developer shall seek prior approval with relevant revisions to this methodology by emailing a request to <u>methodology@goldstandard.org</u>.
- 3.2.5 | If the source of CO_2 is biogenic, the following conditions apply:

- a. The source of CO_2 shall be demonstrable renewable biomass and shall comply with both the criteria defined for renewable biomass in the Clean Development Mechanism (CDM) <u>EB 23 Report Annex 18</u> and any applicable laws and regulations in the host country.
- b. If a biomass treatment facility processes biomass with non-biomass, the project developer shall disclose the share of biomass that was treated at the end of the monitoring period. This methodology applies only to the biogenic fraction.
- c. If the CO₂ is sourced from processes that involve both fossil and biogenic CO₂ emissions, the amount of biogenic CO₂ emissions shall be determined according to the monitoring and reporting regulations of the European Union Emission Trading System (EUR-Lex 02018R2066-20240701 - EN) or equivalent. The amount of stored biogenic CO₂ shall not exceed the total biogenic CO₂ emissions of the respective CO₂ source within the same monitoring period.
- d. The project shall not result in a significant change in production capacity of the source of CO_2 (+/- 25% raw gas production) as compared to the baseline scenario.

3.2.6 | Mineral waste feedstock:

- a. The mineral waste feedstock shall be a demonstrable waste material. The source of the mineral waste shall be documented and monitored as the parameter "Mineral waste source" (Parameter ID 12), as prescribed in <u>Section 7</u>.
- b. There shall be no alternative use of the waste material feedstock, and the project developer shall demonstrate that the project activity does not substitute any current practices. Exceptions may be made if the appropriate leakage emissions are considered in <u>Section 5.7</u>. If project developers wish to apply this exception, they shall seek approval by emailing a request to <u>methodology@goldstandard.org</u>.
- c. Mineral waste feedstocks resulting from fossil fuels (e.g., coal ashes) shall be eligible only when it can be demonstrated that the purchase/use of the feedstock does not contribute to the lock-in of fossil fuels.
- d. Mineral waste feedstocks shall be categorised considering material type (i.e., concrete aggregate, slags), composition, morphology, and baseline end-of-life scenario.

3.2.7 | Carbonated product:

a. The carbonated product shall not be subject to conditions that could negatively impact its durability, i.e., conditions which may promote its decomposition and the subsequent re-release of CO₂. For example, the carbonated product shall not be applied to agricultural soils (e.g., as a fertiliser or pH regulator), used in clinker production, ceramics, or any other processes which require a high temperature, or be at risk of end-of-life waste incineration (see Section 5.10, Reversal Mitigation for further information).

- b. If the carbonated product is used for downstream processes, it shall fulfil the same quality standards as the non-carbonated baseline material and shall not lead to an increase in the embodied emissions. For example, if a carbonated product is used during cement production (after clinker production), the cement which incorporates the carbonated product must fulfil the same quality standards (e.g., compressive strength of final concrete structures) as the baseline cement which does not incorporate a carbonated product while also using the same or a reduced amount of clinker.
- c. The end use of carbonated product shall be monitored on a qualitative basis through parameter "End use of mineral waste" (Parameter ID 20), as prescribed in <u>Section 7</u>.

3.3 | Safeguards

- 3.3.1 | The project shall adhere to Gold Standard <u>Principles & Requirements</u> and <u>Safeguarding Principles & Requirements</u>.
- 3.3.2 | Contractual Obligation: The project developer is solely responsible for meeting all data and monitoring requirements. The project developer shall, by means of direct ownership, contractual agreement, or other such arrangement between them and the relevant project and non-project participants, establish access to the required monitoring data and supporting documentation set forth in this methodology, Gold Standard Principles & Requirements, GHG Emissions Reductions & Sequestration Product Requirements, and applicable activity requirements.
- 3.3.3 | **Double-counting:** To mitigate the risk of double issuance and claims, project developer shall conform with the requirements and apply the procedures set forth in the <u>GHG Emissions Reductions & Sequestration Product Requirements</u> to ensure that no double-counting takes place.
- 3.3.4 | **Health and safety:** Projects shall comply with health and safety requirements at both the organisational level and with the most stringent applicable global standard (e.g., EU Strategic Framework on Health and Safety at Work), in line with Principle 3 of Gold Standard <u>Safeguarding</u> Principles & Requirements. Furthermore, a risk assessment shall be conducted for all hazardous and potentially hazardous materials that are used for the project activity (e.g., solvents and sorbents). Any pollutants (solids, liquids and gases) associated with the project activity shall be addressed in line with Principle 9.4 of Gold Standard <u>Safeguarding Principles & Requirements</u>.
- 3.3.5 | **Sustainability:** When possible, project activities shall regenerate or reuse primary capture materials to minimise the production of waste, in line with Principle 9.5 of Gold Standard <u>Safeguarding Principles & Requirements</u>.

3.4 | Entry into Force

3.4.1 | The date of entry into force of this methodology is 30 days from its publication date.

4| NORMATIVE REFERENCES

- 4.1.1 | This methodology refers to the latest approved versions of the following methodologies, tools, and documents:
 - a. Gold Standard:
 - i. Engineered Carbon Dioxide Removal Activity Requirements
 - ii. TOOL- Reversal Risk Assessment for Mineralised Carbon (*in development*)
 - iii. <u>Methodological TOOL 01 Project or Leakage Emissions From Fossil</u> <u>Fuel Combustion</u>
 - iv. <u>Methodological TOOL 02 Project or Leakage Emissions From</u> <u>Transportation</u>
 - b. CDM¹:
 - i. <u>CDM TOOL01 Tool for the demonstration and assessment of</u> <u>additionality</u>
 - ii. <u>CDM TOOL02 Combined tool to identify the baseline scenario and</u> <u>demonstrate additionality</u>
 - iii. <u>CDM TOOL07 Tool to calculate the emission factor for an electricity</u> <u>system</u>
 - iv. <u>CDM TOOL12 Project and leakage emissions from road</u> <u>transportation of freight</u>
 - v. <u>CDM TOOL16 Project and leakage emissions from biomass</u>
 - vi. <u>CDM TOOL24 Common practice</u>
 - c. Other sources:
 - i. <u>European Union Emission Trading System (EUR-Lex 02018R2066-</u> 20240701 - EN)

5| GREENHOUSE GAS ACCOUNTING METHODOLOGY

5.1 | Project Boundary

5.1.1 | As indicated in Figure 1, the spatial extent of the project boundary includes the physical and geographical site of the source of CO₂, the MRF, the carbonation plant, and the site where the end products, i.e., carbonated products, are used.

¹ CDM Tool referenced shall expire on 31/12/2025.



Figure 1: System boundaries

5.2 | Emissions Sources Included in the Project Boundary

5.2.1 | The following table details the greenhouse gas (GHG) emission sources included in or excluded from the project boundary.

Table 3.	Emissions	Sources	Included	or E	Excluded	from	the	Project	Boundary
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Scenario	Source	Gas	Included	Justification/Explanation
	N/A	CO ₂	Yes	Natural carbonation may occur in the baseline scenario (carbon sink). ²
aseline cenario		CH ₄	No	Baseline scenario does not generate negative or positive emissions.
ŭ D		N ₂ O	No	Baseline scenario does not generate negative or positive emissions.
ject nario	Process operations (P1, P2, P4, P5, P6, P10)	CO ₂	Yes	Emissions relating to electricity production or fuel combustion for energy to power process operations.
Pro scer		CH_4	No	Excluded for simplification.
		N_2O	No	Excluded for simplification.

² Please refer to Sections 5.2.2 |and 5.5.1 |

	Transport activities (P3, P7, P9, P11)	CO ₂	Yes	Emissions relating to electricity production or fuel combustion for energy to power transport
		CH ₄	No	Excluded for simplification
		N_2O	No	Excluded for simplification
-	Embodied emissions for consumables, including solvent supply (P8)	CO ₂	Yes	Emissions relating to electricity production or fuel combustion for energy to power production of solvents.
		CH ₄	No	Excluded for simplification.
		N ₂ O	Yes	Significant nitrous oxide (N2O) emissions may arise during solvent production.
-	Embodied emissions (P12)	CO ₂	Yes	Emissions relating to electricity production or fuel combustion for energy to power production of new infrastructure.
		CH ₄	No	Excluded for simplification.

- 5.2.2 | It shall be demonstrated that the mineral waste feedstock would not undergo significant carbonation (>2% project sink capacity) in the baseline scenario (e.g., if left exposed to atmospheric CO_2 in ambient conditions). If this cannot be demonstrated, carbonation in the baseline scenario shall be accounted for using a conservative discount factor, the derivation of which shall be clearly justified in the project design document (PDD). Further guidance is provided in Section 5.5.1 |
- 5.2.3 | If any of the listed emissions sources do not apply to the project scenario (e.g., the biogenic CO₂ source is located next to the project site, so liquefaction or vehicle transport of CO₂ is not required), then these processes can be excluded from the emissions accounting. Such cases shall be duly described in the respective PDD.
- 5.2.4 | If the project involves the construction of a new CO₂ capture facility that did not exist in the baseline scenario (e.g., a direct air capture [DAC] or pyrolysis plant), the project developer shall apply the relevant Gold Standard methodology in addition to this methodology to account for the associated project and leakage emissions.
- 5.2.5 | If any additional transport activities are deemed significant (i.e., >5% total project emissions from transport, Section 5.6(b)) these shall be included as a project emission source, and the relevant details (e.g., distance and transportation mode) shall be outlined in the PDD.

5.3 | Demonstration of Additionality

- 5.3.1 | The project shall demonstrate additionality through regulatory surplus supplemented with financial analysis and common practice. Further requirements are outlined below.
- 5.3.2 | Regulatory surplus analysis
 - a. All activities, regardless of their scale, shall demonstrate regulatory surplus. This means showing that the proposed activity is not directly mandated by law or triggered by any legal requirements, such as legally binding agreements, covenants, consent decrees, or enforced contracts with government agencies or private parties.
 - b. At each verification, the project shall conduct the regulatory surplus check, and if a legal mandate is enforced during the crediting period, the project can claim credits only until the day the legal requirements become effective.
- 5.3.3 | Financial viability analysis
 - a. The project developer shall demonstrate financial viability by conforming to additionality requirements and applicable guidelines of latest version of one of the following standard documents or provisions:
 - i. <u>CDM TOOL01 Tool for the demonstration and assessment of</u> <u>additionality</u> or applicable A6.4 additionality tool as approved for use under GS4GG, or
 - ii. <u>CDM TOOL02 Combined tool to identify the baseline and</u> <u>demonstrate additionality</u> or applicable A6.4 additionally tool as approved for use under GS4GG, or
 - iii. An approved Gold Standard additionality tool.
 - b. The project developer shall provide transparent and consistent³ documented evidence to demonstrate the additionality in line with the applied additionality tool and applicable guidelines.
 - c. Where benchmark analysis is conducted for investment analysis, it shall transparently demonstrate that:
 - i. the project would not meet the required financial benchmark without carbon credit revenues, and
 - ii. the economic performance of the project increases decisively through carbon credit revenues, and
 - iii. carbon credit revenues can raise the economic performance at or above the required financial benchmark.
 - d. Where investment comparison analysis is conducted, it shall transparently demonstrate that:

³ Consistent with information presented to the company's decision-making management and investors/lenders.

- i. the alternative scenarios considered are mutually exclusive and provide the same type of products or service levels as the project activity, where applicable, and
- ii. the project activity would not be the economically most attractive scenario in absence of carbon credits.
- e. Where simple cost analysis is conducted, it shall transparently demonstrate that:
 - i. carbon credit revenue can ensure sustained operation of the activity throughout its entire crediting period.
- 5.3.4 | Common practices
 - a. The project developer shall demonstrate that project activity is not common practice by applying the latest version of <u>CDM TOOL24</u> -<u>Common practice</u>.⁴
 - b. The project activity shall be considered common practice within a sector in the applicable geographical area if the outcome of the assessment is greater than 20%.
- 5.3.5 | Simplified procedure to demonstrate additionality
 - a. For the Programme of Activities (PoA), the coordinating and managing entity (CME) can consider new, regular-case Voluntary Project Activities (VPAs) as additional for up to three years from the decision-making of the real-case VPA if:
 - i. the real-case VPA is shown to be additional, and
 - ii. the financial analysis parameters (costs and revenues) for the regular-case VPA are within +/- 10% of those used for the real-case VPA, and
 - iii. the regular-case VPA is not a common practice at the time of inclusion.
 - b. For a VPA (regular or real case) that involves the implementation of multiple facilities of similar scale, the simplified procedure can be used for new facilities for up to three years from the decision-making of the first facility. In such cases:
 - i. The assessment for the first facility, which meets the requirements in Sections 5.3.2–5.3.4, shall be used as a benchmark.
 - ii. A common practice analysis is not needed.
- 5.3.6 | The project developer shall conduct the reassessment of additionality elements at the time of renewal of crediting period as follows:
 - a. Regulatory surplus
 - b. Ongoing financial needs per GS4GG requirements

⁴ Similar CDM or other voluntary projects validated by an official carbon standard and dependent on carbon revenue shall not be included in this analysis (Section 4.5.2., Paragraph 60).

5.4 | Baseline Scenario

- 5.4.1 | Project developers shall apply the latest approved version of <u>CDM TOOL02</u> -<u>Combined tool to identify the baseline and demonstrate additionality</u> to identify the most plausible baseline scenario among all realistic and credible alternatives.
- 5.4.2 | Project developers shall consider all realistic and credible baseline scenarios for both the CO_2 and the feedstock material, consistent with applicable regulations in the host country or region (see <u>Annex 2</u> for example scenarios).
- 5.4.3 | If more than one credible and plausible alternative scenario remains, the project developer shall select the scenario corresponding with the lowest baseline emissions as the baseline scenario.
- 5.4.4 | This methodology is eligible only for projects with no enhanced carbonation in the baseline scenario, i.e., CO₂ is emitted directly or indirectly to the atmosphere, and the mineral waste is generated and used or disposed of without carbonation.

5.5 | Baseline Removals

- 5.5.1 | Removals in the baseline may occur due to natural carbonation of the mineral waste feedstock in ambient conditions. These removals shall be accounted for where significant (>2% project sink capacity).
- 5.5.2 | Baseline removals shall consider the total amount of CO₂ that would have been removed by each material type in the baseline scenario over the timeframe for which the material would have been exposed to CO₂. The total value (tCO₂) shall be divided over the crediting period to give an annualised value.
- 5.5.3 | The timeframe for which natural carbonation is considered, *x*, shall describe the average duration for which natural carbonation could occur in the baseline scenario (e.g., number of years a mineral waste pile is exposed to the ambient atmosphere). If a project-specific value cannot be obtained, *x* shall be set to the durability timeframe (e.g., 1,000 years).

The ex-ante baseline carbonation, $BR_{ex-ante,y}$, shall be calculated as follows:

$BR_{y} = \frac{nat.carb_{i,x}}{CP}$					
Where:					
BR_y	=	Baseline carbonation for the monitoring period γ , (tCO ₂)			
nat.carb _{i,x}	=	Quantity of CO_2 removed by the forecast quantity of material <i>i</i> across the total specified time period <i>x</i> , (t CO_2)			
i	=	Material type <i>i</i> , i.e., category of mineral waste			
Х	=	The timeframe for which natural carbonation is considered (years)			

CP = Crediting period length (years); or set value to 1 to account for all baseline removals within the first year.

- 5.5.4 | Natural carbonation shall be determined for each material type (*i*) considering relative end-of life scenarios. Natural carbonation may consider material composition and morphology (e.g., grain size) as well as environmental conditions which impact CO₂ uptake, such as temperature, precipitation, humidity, rainwater and groundwater pH, carbonate saturation, and microbial activity. Natural carbonation may also consider the nature of interaction with the ambient atmosphere, for example, if only the top layer of a mine tailings pile is exposed.
- 5.5.5 | Derivation of the natural carbonation shall be detailed in the PDD and shall be subject to validation.
- 5.5.6 | For micro- and small-scale projects, natural carbonation shall be determined using laboratory studies or relevant literature. For large-scale projects, natural carbonation shall be determined via project-specific laboratory studies.

5.6 | Project Removals (Project Sinks)

- 5.6.1 | The carbonation of reactive mineral waste serves as a durable storage solution, i.e., carbon sink. Therefore, the term "project sinks" is applied instead of the term "baseline emissions" in subsequent sections.
- 5.6.2 | The project sinks are equivalent to the amount of CO₂ sequestered in the carbonated product by applying direct or indirect mineral carbonation (i.e., formation of stable carbonate minerals).

a. Ex-Ante Quantification of Project Sinks

5.6.3 | The ex-ante project sink, $PS_{ex-ante,y}$, shall be calculated using the mass of subfractions of the mineral waste, $MG_{rep,i,d}$, and the sink factor of each subfraction, $SF_{i,d}$, following the equation below:

$$PS_{ex-ante,y} = \sum_{i=1}^{n} \sum_{d=1}^{m} MG_{rep,i,d} * SF_{i,d}$$

Eq. 2

Where:

PS _{Ex-ante,y}	=	Ex-ante CO ₂ sequestration in the monitoring period y of the respective project sink (t CO ₂)
MG _{rep,i,d}	=	Representative, cumulative mass of subfractions <i>d</i> and material <i>i</i> (t mineral waste) based on historical data or forecast
SF _{i,d}	=	Sink factor corresponding to the specific amount of CO_2 that can be durably fixed in the material <i>i</i> of grain size <i>d</i> (t CO_2 /t mineral waste)
i	=	Material of type <i>i</i> ; can be distinguished based on chemical composition, reports, or internal considerations of the materials recovery facility

- 5.6.4 | The sink factor of each subfraction, $SF_{i,d}$, is a function of the quality of the material of type *i* and the grain size *d*. The values used for $SF_{i,d}$ must be provided in the PDD with relevant justification and references and may be:
 - a. determined via experimental methods through, for example, sieving (SN EN 12620 5), or
 - b. based on previous measurements at industrial scale, or
 - c. extracted from reports, data sheets, or scientific literature.

b. Ex-Post Quantification of Project Sinks

5.6.5 | The ex-post project sink, $PS_{ex-post,y}$, shall be calculated using the CO₂ input to and lost from the reactor system ($m_{CO_2,i,d}^{in}$ and $m_{CO_2,i,d}^{out}$, respectively) per the following equation:

$$PS_{ex-post,y} = \sum_{i=1}^{n} \sum_{d=1}^{m} \left(m_{CO_{2id}}^{in} - m_{CO_{2id}}^{lost} \right)$$
Eq. 3

Where:

PS _{ex-post,y}	=	The project sink for the monitoring period y (t CO ₂)
$m^{in}_{CO_2,i,d}$	=	Mass of CO_2 fed into the carbonation process in the monitoring period y (t CO_2)
$m^{lost}_{CO_2,i,d}$	=	Mass of CO_2 exiting the carbonation process in the monitoring period y (t CO_2) which was not stored in material <i>i</i> and grain size <i>d</i> during the monitoring period y (t CO_2)

5.6.6 | For input to Equation 3, the mass of CO_2 exiting the carbonation process during **solid-state direct carbonation**, $m_{CO_2,i,d}^{lost}$, shall be calculated using the following equation:

$$m_{CO_2,i,d}^{lost} = m_{CO_2,i,d}^{out} + \frac{p*M_{CO_2}}{R*T} * \epsilon_{i,d} * \frac{y_{i,d}^{CO_2}}{\rho_{bulk,i,d}} * MG_{y,i,d}$$
Eq. 4

Where:

$m_{CO_{2,i,d}}^{out}$	=	Mass of CO_2 exiting the reaction chamber through an outlet pipe during the monitoring period y (t CO_2)
M_{CO_2}	=	The molar mass of CO_2 (t/mol)
р	=	The total pressure of the air (Pa)
R	=	The ideal gas constant [8.3145 J/(mol K)]
Т	=	The ambient temperature (K)
$\epsilon_{i,d}$	=	The gas void fraction per m^3 for material <i>i</i> and grain size <i>d</i> (unitless)
$y_{i,d}^{CO_2}$	=	CO_2 molar fraction (unitless)
$ ho_{bulk,i,d}$	=	Bulk density of material type <i>i</i> and grain size d (kg/m ³)

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⁵ SN EN 12620+A1:2008 | SNV

MG_{y,i,d} = The cumulative mass of subfractions d and material i processed within the monitoring period y (t mineral waste)

5.6.7 | The gas void fraction, ϵ_I , is the space between the mineral waste particles which can be filled with gas (Figure 2). It shall be calculated as follows:



Figure 2: Schematic illustration of inlet, and if available, outlet gas streams in relation to the carbonation container. For solid-state direct mineral carbonation, an additional term relative to gas losses in void volume is also represented.

$$\epsilon_{i,d} = 1 - \frac{\rho_{bulk,i,d}}{\rho_{i,d}}$$
 Eq. 5

Where:

 $\rho_{i,d}$ = Grain density of material type *i* and grain size *d* (kg/m³)

- 5.6.8 | For input to Equation 3, the mass of CO_2 exiting the carbonation process during **direct aqueous state/slurry carbonation**, $m_{CO_2,i,d}^{lost}$, is negligible as the inflow of CO_2 is optimised to prevent bubbling and CO_2 release from the tank (see <u>Annex 1</u> for further information). Direct aqueous state/slurry carbonation shall be referred to as slurry carbonation throughout the text for simplification.
- 5.6.9 | For input to Equation 3, the mass of CO_2 exiting the carbonation process during **indirect mineral carbonation**, $m_{CO_2,i,d}^{lost}$, corresponds to the mass of CO_2 measured in the outlet pipe. This is because the reaction happens in aqueous medium, meaning no void losses are considered. It is therefore calculated as follows:

 $m_{CO_2,i,d}^{lost} = m_{CO_2,i,d}^{out}$

Eq. 6

c. Validation of Project Sink Calculations

5.6.10 |It shall be demonstrated that the CO₂ is stored in the form of durable carbonate minerals and that the methods outlined above are accurate and conservative. This shall be demonstrated by comparison with results from the direct analysis of the feedstock(s) pre- and post-carbonation using techniques such as X-ray diffraction. At minimum, demonstration is required at the onset of each crediting period for each material type (*i*) prior to first issuance

request for the crediting period, and each time a new material type is introduced.

5.6.11 |Where discrepancies are observed, a conservative discount factor shall be applied to project sink calculations. The discount factor may be determined based on the difference between the direct and indirect methods described above. Alternatively, a literature-based discount factor may be applied to account for uncertainty between the two methods.

5.7 | Project Emissions

5.7.1 | The project emissions in year y, PE_y , shall be determined by considering the emissions from electricity/fuel consumption for operations ($PE_{op,y}$), electricity/ fuel consumption for transport activities ($PE_{tr,y}$), and embodied emissions ($PE_{em,v}$). Therefore, PE_v shall be calculated as follows:

$$PE_y = PE_{op,y} + PE_{tr,y} + PE_{em,y}$$

Eq. 7

Where:

PEy	=	Project emissions in year y (tCO ₂ e)
PE _{op,y}	=	Project emissions from process operations in monitoring period y (t CO ₂ e)
PE _{tr,y}	=	Project emissions from transport activities applications in monitoring period y (t CO ₂ e)
PE _{em,y}	=	Embodied project emissions applications in monitoring period y (t CO ₂ e)

a. Project Emissions from Electricity and/or Fuel Consumption for Process Operations

5.7.2 | Project emissions associated with electricity and/or fuel consumption for process operations ($PE_{op,y}$) shall be calculated as follows:

$$PE_{op,y} = PE_{op,capture,y} + PE_{op,liquefaction,y} + PE_{op,ref,y} + PE_{op,processing,y}$$
Eq. 8
+ PE_{op,carbonation,y} + PE_{op,min,y}

Where:

 $PE_{op,capture,y}$ = Project emissions associated with the electricity and/ or fuel consumption required for the capture and separation of CO₂ in the monitoring period y (t CO₂e). If the carbonation plant is located at the CO₂ source and the CO₂ is sourced directly from the off-gas, then $PE_{capture,st,y} = 0$. (P1) $PE_{op,liquefaction,y}$ = Project emissions associated with the electricity and/ or fuel consumption required for CO₂ liquefaction in the monitoring period y (t CO₂e). If the carbonation

plant is located at the CO_2 source and the CO_2 is

sourced directly from the off-gas, then $PE_{liquefaction,st,v} = 0.$ (P2)

- $PE_{op,ref,y}$ = Project emissions associated with the electricity and/ or fuel consumption required for the refrigeration of CO₂. If a vacuum isolated tank is used without the requirement of refrigeration, then $PE_{op,ref,y} = 0$. (P4)
- $PE_{op,processing,y}$ = Project emissions associated with the electricity and/ or fuel consumption required for the processing of CO_2 for carbonation (e.g., evaporation) in the monitoring period y (t CO_2e). If CO_2 is sourced directly from the source off-gas and injected directly into the reaction chamber, $PE_{op,processing,y} = 0$. (P5)
- $PE_{op,carbonation,y}$ = Project emissions associated with the electricity and/ or fuel consumption required for the operation of the carbonation plant in the monitoring period y (t CO₂e). (P6)
- $PE_{op,min,y}$ = Project emissions associated with the electricity and/ or fuel consumption required for the additional processing of mineral waste feedstock(s) in monitoring period y (t CO₂e). If no additional electricity and/or fuel consumption is required for the processing of mineral waste feedstock(s) in relation to the baseline, $PE_{op,min,y} = 0$. (P10)
- 5.7.3 | For input to Equation 7, each term $PE_{x,st,y}$ (where x represents a specific process operation) shall be calculated as follows:

$$PE_{pop,y} = PE_{op,electricity} + PE_{op,fuel}$$
 Eq. 9

Where:

PE _{op,electricity}	=	Project emissions associated with electricity
		consumption for process operations in monitoring
		period γ (t CO ₂ e)
DE	_	Droject emissions accessized with fuel consumption

- $PE_{op,fuel}$ = Project emissions associated with fuel consumption for process operations in monitoring period y (t CO₂e)
- 5.7.4 | For input to Equation 8, the emissions from electricity consumed for process operations, PE_{op.electricity}, shall be calculated as follows:

$$PE_{op,electricity} = \sum (EC_{x,y} \times EF_y)$$
Eq. 10

Where:

$EC_{x,y}$	=	Electricity consumed by the process operation x in monitoring period y (MWh)
$EF_{x,y}$	=	Emission factor for the electricity consumed by the process operation x in year y (tCO ₂ /MWh)

- 5.7.5 | For input to Equation 8, the emissions associated with fuel consumption for process operations, $PE_{st,fuel}$, shall be calculated according to Gold Standard Methodological TOOL 01 - Project or Leakage Emissions From Fossil Fuel Combustion.
 - b. Project Emissions from Electricity and/or Fuel Consumption for Transport **Activities**
- 5.7.6 | Project emissions associated with electricity and/or fuel consumption for transport activities, $PE_{tr,v}$, shall be calculated as follows:

$$PE_{tr,y} = PE_{tr,capture,y} + PE_{tr,equipment,y} + PE_{tr,mineral,y} + Eq. 11$$

 $PE_{tr,product,y}$
Vhere:

V

- Project emissions associated with the transport of CO₂ PE_{tr,capture,v} from the site of capture to the carbonation plant during the operation of the carbonation plant during the monitoring period y (t CO₂e). (P3)
- Project emissions associated with the transport of PE_{tr,equipment,y} =mobile carbonation equipment to the carbonation site (e.g., vaporisers, process control units, etc.) in the monitoring period y (t CO₂e). If the carbonation plant is stationary, $PE_{tr,equipment,y} = 0.$ (P7)
- Project emissions associated with the additional PE_{tr,mineral,,y} = transport of mineral waste feedstock(s) to the carbonation plant during the operation of the carbonation plant in the monitoring period y (t CO₂e). If no additional transport of mineral waste feedstock(s) is required in relation to the baseline, $PE_{tr.mineral.v} = 0.$ (P9)
- Project emissions associated with the additional PE_{tr,product,y} = transport of the carbonated product to the site of use or disposal during the monitoring period y (t CO₂e). If no additional transport of carbonated mineral waste feedstock(s) is required in relation to the baseline, $PE_{tr,product,y} = 0.$ (P11)
- Project emissions associated with any other significant PE_{tr.other.v} = transport activities (>5% total transport emissions) during the monitoring period y (t CO₂e). If there are no such activities, $PE_{tr,other,y} = 0$.
- 5.7.7 | For input to Equation 10, each term $PE_{x,tr,y}$ (where x represents a specific transport activity) shall be calculated using:
 - a. <u>CDM TOOL12</u> for the transport of freight, or
 - b. Gold Standard Methodological TOOL 02 for transport (non-freight).

c. Embodied Emissions

5.7.8 | Embodied emissions for the project activities, $PE_{em,y}$, shall be calculated as follows:

	$PE_{em,y} = P$	$E_{consumables,y} + PE_{infra,tr,y}$	Eq. 12
Where:			
$PE_{consumables,y}$	=	Embodied emissions associated with significant consumables, including so $(>5\% \text{ project emissions})$ during the period <i>y</i> (t CO ₂ e) (P8)	the Ivent supply monitoring
PE _{infra,tr,y}	=	Embodied emissions associated with infrastructure during the monitoring (t CO ₂ e) (P12)	new period <i>y</i>

5.7.9 | For input to Equation 12, the embodied emissions from significant consumables (including solvent supply), *PE_{consumables,y}*, shall be calculated as follows:

$$PE_{consumables,y} = SC_y * EF_{consumable}$$
 Eq. 13

Where:

SCy	=	Consumption of consumable within the project
		boundary during the monitoring period y (tonnes)
EF _{consumable}	=	Emission factor of the consumable which considers its entire life cycle; for example, refer to databases such
		as Ecoinvent (t CO ₂ e /t consumable)

- 5.7.10 |For input to Equation 12, the embodied emissions from the construction of new infrastructure (e.g., new carbonation plants) shall be accounted for using a cradle-to-gate assessment of the emissions generated by the production of raw materials of key components, (e.g., steel) over an average operational lifetime of the facility (e.g., 20 years). Default values for new infrastructure shall be detailed in the PDD with relevant justifications. Example default factors for Neustark carbonation plants over a facility lifetime of 20 years are given in Section 5.7.(h), Parameter ID 11.
- 5.7.11 |Project emissions may arise due to venting and fugitive losses of CO₂ from the project infrastructure. However, because the CO₂ originates from atmospheric or sustainable biomass sources, these emissions are considered neutral and are therefore not accounted for.

5.8 | Leakage Emissions

5.8.1 | Leakage may occur if the project leads to a shift in the use of materials compared to the baseline scenario. To demonstrate that this leakage does not occur, the project developer shall provide documentation to show that there was no alternative use for the waste material(s) in the baseline scenario. This documentation shall detail the source and fate of the waste materials (historical or forecast) and shall be submitted at the start of the crediting

period with a forecast for the remaining crediting or shall be included in each monitoring report.

- 5.8.2 | If the above cannot be demonstrated, the project developer shall detail baseline use(s) of the material and shall conservatively account for the resulting leakage.
- 5.8.3 | Leakage may also occur due to an increase in the production of biogenic CO₂. If the project activity sources CO₂ from an existing biomass treatment facility with a production capacity limited by feedstock and upgrading technology, no leakage considerations are required.
- 5.8.4 | If the project activity sources CO₂ from a new biomass treatment facility and the project results in a change in production capacity of the source of CO₂ higher than +/- 25% (raw gas production) as compared to the baseline scenario (see Eligibility criteria 3.2.5 |d), such variation must be explained in the monitoring report, and leakage considerations are required as detailed in Section 5.8.5 |
- 5.8.5 | Total leakage emissions in year y, Ley, are determined as follows:

$$LE_{y} = \sum_{i} (LE_{L1_{ff,y}} + LE_{L2_{ff,y}})$$

Where:

$$LE_{L1_{ff,y}} = Leakage from biomass at biomass treatment facilityff in year y (t CO_2e)$$
$$LE_{L2_{ff,y}} = Leakage from biomass due to beneficial combustionat biomass treatment facility ff in year y (t CO_2e)$$

- a. The project may capture CO_2 from the processing of renewable biomass from new or existing biomass facilities. Various approaches are required to determine leakage from biomass at facility *ff* in year *y*, $LE_{L1_{ffy}}$:
 - *i.* Where the biomass has been demonstrated to conform with the conditions per option 1 of monitoring parameter Renewability of $\operatorname{biomass}_{ff,n,y}$, the renewable energy products produced by the biomass treatment facility are subject to pressures (incentives, quota, renewable fuel content requirements, or other) from the jurisdictional or host country standards, regulations, or programmes that promote the use of renewable energy. In this situation, the project does not contribute to positive leakage from biomass outside the project boundary; therefore, leakage from biomass at facility *ff* in year *y*, $\operatorname{LE}_{L1_{ffy}}$ is assumed to be zero.
 - *ii.* Where the biomass has been demonstrated to conform with the conditions described for option 2 of monitoring parameter Renewability of $\operatorname{biomass}_{ff,n,y}$, the project developer shall estimate leakage from biomass at facility *ff* in year *y*, $\operatorname{LE}_{L1_{ff,y}}$, in accordance with CDM TOOL16.

Eq. 14

b. Biomass may be combusted to the benefit of the project, such as to generate electricity or heat consumed by the project. The project developer shall estimate the leakage from biomass due to beneficial combustion at facility *ff* in year *y*, $LE_{L2_{ff,y}}$, in accordance with CDM TOOL16. This estimation shall consider all quantities of biomass combusted to the benefit of the project, regardless of the renewability of that biomass.

5.9 | Carbon Removals

5.9.1 | If the project sources biogenic CO₂ from an existing facility which does not require accounting from an additional Gold Standard–approved methodology, the total CO₂ removals shall be calculated as follows:

$$ER_{y} = PS_{y} - PE_{y} - LE_{y} - BR_{y}$$
Eq. 15

Where:

ER_y	=	CO_2 removed during the monitoring period y due to
		the project activity (t CO_2e)
PS_y	=	Project sinks in the monitoring period y (t CO ₂ e)
PEy	=	Project emissions in the monitoring period y (t CO ₂ e)
LEy	=	Leakage emissions in the monitoring period y (t CO ₂ e)
BRy	=	Baseline removals via natural carbonation in the monitoring period y (t CO_2e)

5.9.2 | If the project sources biogenic or atmospheric CO₂ from new facilities (i.e., facilities that did not exist in the baseline scenario), the project developer shall apply the relevant Gold Standard–approved TOOL X (in development) to account for the total CO₂ removals.

5.10 | Reversal Mitigation

- 5.10.1 |The project developer shall document and include, as part of the PDD, appropriate evidence for all probable end-of-life scenarios⁶ of the carbonated product. It must be demonstrated that there is no significant risk of carbon being rereleased at the product's end of life, such as through municipal solid waste incineration (MSWI). If this cannot be demonstrated, the storage of CO₂ is considered by default to be non-durable.
- 5.10.2 |The project developer shall determine the potential risk of reversal at each verification following TOOL X: Reversal Risk Assessment for Mineralised Carbon (in development).

⁶ For example, if the carbonated product is used as a building material, what is the average lifetime of that building type in the project-specific region, and what are the typical demolition and waste disposal practices (taking into account relevant regulations)?

- 5.10.3 |The project developer shall contribute GS-VERs to the Gold Standard buffer pool corresponding to the highest of the following options:
 - a. The reversal risk score determined per TOOL X: Reversal Risk Assessment for Mineralised Carbon (in development), or
 - *b.* The default value of 2.5% of the CO₂ removals.
- 5.10.4 |In the event of a reversal, the steps outlined in the Engineered Carbon Dioxide Removal Activity Requirements shall be followed.

5.11 | Changes Required for Methodology Implementation at the Time of Crediting Period Renewal

- 5.11.1 |At the time of the crediting period renewal, the project shall:
 - a. Reassess the continued validity of the baseline in line with any changes in the relevant national and/or sectoral regulations and incorporate the impact of new regulations on baseline.
 - b. Update the baseline emissions using the latest available data.
 - c. Update the ex-ante parameter values (that were not updated during the crediting period).
 - d. Incorporate any relevant updates to the GS4GG requirements as applicable to the project activity.
- 5.11.2 | For the renewal of the crediting period, the project shall apply the latest available version of the methodology.

5.12 | Data and Parameters Not Monitored

5.12.1 |In addition to the data and parameters listed in the following table, the guidance on all tools to which this methodology refers shall apply. Thus, it is also recommended to refer to specific guidelines and tools applied in the methodology, as not all parameters may be listed in this section.

Parameter ID	1
Data/Parameter:	MG _{rep,i,d}
Data unit:	t
Description:	Representative, cumulative mass of subfractions <i>d</i> and material <i>i</i> (t mineral waste) based on historical data or forecast
Source of data:	Historical production of mineral waste or forecast
Measurement procedures (if any):	-
Any comment:	For ex-ante calculations, only the historical material throughput values employed in use cases that ensure the permanence of CO_2 shall be considered.

Parameter ID	2
Data/Parameter:	<i>SF_{i,d}</i>
Data unit:	t CO2e/t material
Description:	Sink factor corresponding to the specific amount of CO2 that can be fixed in the material i of grain size d through mineralisation (t CO2/t mineral waste)
Source of data:	Determined in experiments, based on previous industrial tests, or sourced from reports or scientific literature
Measurement procedures (if any):	-
Any comment:	-

Parameter ID	3
Data/Parameter:	р
Data unit:	Pascal
Description:	Average annual local ambient pressure
Source of data:	Annual pressure measured close by, e.g., at a weather station. Default:101,325 Pa (standard pressure)
Measurement procedures (if any):	-
Any comment:	-

Parameter ID	4
Data/Parameter:	Т
Data unit:	Kelvin
Description:	Average annual ambient temperature of the project location
Source of data:	On-site measurement or publicly available sources, e.g., weather station report from area close by.

Measurement procedures (if any):	-
Any comment:	-

Parameter ID	5
Data/Parameter:	M _{CO2}
Data unit:	t/mol
Description:	Default molar mass of CO ₂
Source of data:	0.000044 kg/mol
Measurement procedures (if any):	-
Any comment:	-

Parameter ID	6
Data/Parameter:	$ ho_{bulk,i,d}$
Data unit:	kg/m³
Description:	Bulk density of material of type <i>i</i> of grain size <i>d</i>
Source of data:	Options in order of preference:
	a. Measured once according to the norm SN EN 1097-3 (or equivalent)
	b. Reports, data sheets, or scientific literature
	c. Default value for concrete aggregate: 1500 kg/m ³
Measurement procedures (if any):	-
Any comment:	Measured once at the beginning of the project

Parameter ID	7
Data/Parameter:	<i>ρ_{i,d}</i>
Data unit:	kg/m ³

Description:	Density of material of type <i>i</i> of grain size <i>d</i>
Source of data:	 Options in order of preference: a. Measured once according to the norm SN EN 1097-6 (or equivalent) b. Reports, data sheets, or scientific literature c. Default value for concrete aggregate: 2400 kg/m³
Measurement procedures (if any):	-
Any comment:	Measured once at the beginning of the project

Parameter ID	8
Data/Parameter:	R
Data unit:	J/(mol K)
Description:	Ideal gas constant
Source of data:	8.3145
Measurement procedures (if any):	-
Any comment:	-

Parameter ID	9
Data/Parameter:	$EF_{x,y}$
Data unit:	tCO ₂ /MWh
Description:	Emission factor for the electricity consumed by the process operation x in year y
Source of data:	If the project/activity is located in Annex 1 countries:
	a. Official grid emission factors published by host country governments
	b. Grid emission factors published by open access real-time databases combined from national agencies, such as <u>https://app.electricitymaps.com/</u> . In such case, average emission factors covering the reporting period shall be used.

	c. Grid emission factors published as CDM standardised baseline approved by the CDM Executive Board.
	If the project/activity is located in non-Annex 1 countries:
	a. Applying latest version of CDM TOOL07: <u>Tool to calculate the</u> <u>emission factor for an electricity system</u>
	 Official grid emission factors published by host country governments
	c. Grid emission factors published as CDM standardised baseline approved by the CDM Executive Board
Measurement procedures (if any):	-
Any comment:	

Parameter ID	10
Data/Parameter:	EF _{consumable}
Data unit:	t CO ₂ e /t consumable
Description:	Emission factor of the consumable which considers its entire life cycle.
Source of data:	The emission factor can be sourced from databases published by third parties (e.g., Ecoinvent).
Measurement procedures (if any):	-
Any comment:	-

Parameter ID	11
Data/Parameter:	PE _{infra,tr,y}
Data unit:	t CO2e/year
Description:	Embodied emissions associated with new infrastructure during the monitoring period γ
Source of data:	Cradle-to-gate assessment of emissions generated by the production of raw materials of key components (e.g., steel) are given over an average operational lifetime of the facility of 20 years. Existing equipment was excluded from the calculation of

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embodied emissions. Examples of default values for neustark plants are given below:

	Plant type	PE _{embodied,y} (t CO ₂ e/year)
	Retrofitted plant	7
	New plant, capacity volume $\leq 100 \text{ m}^3$	9
	New plant, capacity volume 100-150 m ³	14
	New plant, capacity volume > 150 m^3	20
	New standalone slurry plant	3
	New slurry plant (add on existing system)	negligible
	New standalone fabric plant ⁷	6
	New fabric plant ⁷ (add on existing system)	2
	Estimations of embodied emissions taken from republications can also be used.	eports or scientific
Measurement procedures (if any):	-	
Any comment:	Since the embodied emissions are calculated for of 20 years, if the crediting period is extended be yearly accounting for embodied emissions shall c the entire amount has been accounted cumulativ	the typical lifetime eyond that, the ease to zero once ely.

6| UNCERTAINTY QUANTIFICATION

- 6.1.1 | Potential sources of uncertainty, along with the associated quality assurance/quality control requirements to minimise them, are summarised in the monitoring parameter tables in <u>Section 7</u>.
- 6.1.2 | The uncertainties associated with the parameters shall be aggregated into uncertainty estimates for emission removals. A 95% confidence interval shall be employed for quantifying uncertainty due to random errors, following the statistical approaches provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories and 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (propagation of errors method), unless otherwise required in the applied tool or guidelines. When the uncertainty in the estimated value of emission reductions or removal is expected to be at a 95% confidence interval (within +/-10% range when applicable), the activity may exclude such

⁷ Impact of fabric plants based on weighted lifetime of one year for the fabric and 20 years for the remaining equipment

random errors, while in case of being outside +/-10% range at a 95% confidence interval, the activity should include such random error.

7| MONITORING METHODOLOGY

- 7.1.1 | In addition to the data and parameters listed below, the guidance on all tools to which this methodology refers shall apply. Thus, it is also recommended to refer to specific guidelines and tools applied in this methodology, as not all parameters may be listed in this section.
- 7.1.2 | The project developer shall demonstrate that there is no likelihood that the reactor system shall leak by submitting reactor diagrams and/or monitoring reports with the PDD.

Parameter ID	12
Data/Parameter:	$MG_{y,i,d}$
Data unit:	t
Description:	Mass of the mineral waste type i of a grain size distribution d in monitoring period y
Source of data:	Mass or volume-based measurements or estimates
Measurement procedures (if any):	Material throughput shall be obtained by any of the following methods, by order of preference:
	a. Mass or volume-based measurements.
	b. Estimates considering the maximum of useful volume of the reaction chamber and specific or averaged material density (monitored in Parameter ID 6). Maximum volume estimates of the reaction chamber taken from equipment specification sheets of engineering drawings shall be used if effective useful volume cannot be demonstrated.
QA/QC procedures:	-
Monitoring frequency:	Continuously, aggregated to the total amount per monitoring period
Any comment:	-

7.2 | Data and Parameters Monitored

Parameter ID	13
Data/Parameter:	$m^{in}_{CO_2,i,d}$

Data unit:	t CO ₂
Description:	Mass of CO_2 fed into the carbonation process containing material type <i>i</i> of grain size <i>d</i> , within the monitoring period <i>y</i> .
Source of data:	On-site measurements. The gas flow rate is measured through a calibrated mass flow meter. In case the gas is not pure CO_2 (CO_2 concentration below 98%), the composition may be measured with a corresponding device. To minimise the gas loss to the atmosphere, the saturation of the material <i>i</i> and grain size <i>d</i> with respect to the CO_2 uptake is measured directly or indirectly with a sensor, and the gas flow rate is adjusted correspondingly.
Measurement procedures (if any):	-
QA/QC procedures:	Measured results shall be cross-checked with the amount of the liquefied CO_2 purchased (invoices/liquefied CO_2 trucks' weight measurement records).
Monitoring frequency:	Continuously, during carbonation unit operation and aggregated to the total amount per monitoring period.
Any comment:	-

Parameter ID	14
Data/Parameter:	$m_{CO_{2,i,d}}^{out}$
Data unit:	t CO ₂
Description:	Mass of CO_2 exiting the reaction chamber through an outlet pipe containing material type <i>i</i> of grain size <i>d</i> during the monitoring period <i>y</i> (t CO_2).
Source of data:	On-site measurements. The plant shall be equipped with a device measuring the flow rate and composition of the exiting gas stream. These two numbers allow determination of the amount of CO_2 exiting the process in the monitoring period y .
Measurement procedures (if any):	-
QA/QC procedures:	Measured results shall be cross-checked with previously obtained results of other project sinks.

Monitoring frequency:	Continuously, during plant operation and aggregated to the total amount per monitoring period.
Any comment:	-

Parameter ID	15
Data/Parameter:	$y_{i,d}^{CO_2}$
Data unit:	Mole CO ₂ /mole gas (unitless)
Description:	CO ₂ molar fraction
Source of data:	Options to determine $y_{i,d}^{CO_2}$:
	a. A dedicated CO_2 concentration sensor measures the CO_2 concentration in the gas phase between the particles as they are discharged from the system. This concentration can be monitored continuously or over 10 process cycles and shall be recalibrated regularly.
	b. Use a conservative estimate $y_{i,d}^{CO_2} = 1$.
Measurement procedures (if any):	-
QA/QC procedures:	-
Monitoring frequency:	Measured annually in industrial operation.
Any comment:	This value shall be validated on a recurring basis.

Parameter ID	16
Data/Parameter:	$EC_{x,y}$
Data unit:	MWh
Description:	Electricity consumption of process x in the monitoring period y .
Source of data:	Measurement of electricity consumption can be done by:
	a. Electric meter on-site (preferred source), or
	 b. Conservative consumption value from specific equipment technical specifications.

Measurement procedures (if any):	-
QA/QC procedures:	-
Monitoring frequency:	Continuously over the monitoring period y.
Any comment:	For determination of ex-ante emission removals, the specific electricity consumption of the specific process component (e.g., liquefaction, vaporiser, process control) as mentioned in its technical specification sheet or from comparative facility shall be used (in MWh/t CO_2). For the electricity consumption of liquefaction: Given that one liquefaction plant may deliver to different storage sites, electricity consumption may be given in annual consumption per tonne of CO_2 liquefied, multiplied by the CO_2 delivered to the storage site.

Parameter ID	17
Data/Parameter:	<i>SC</i> _y
Data unit:	Tonne
Description:	Consumption of consumable within the project boundary during the monitoring period y
Source of data:	Using scales, flow meters on-site, or purchasing reports
Measurement procedures (if any):	-
QA/QC procedures:	Cross-check with transport bills
Monitoring frequency:	Continuously
Any comment:	Used for indirect carbonation process

Parameter ID	18
Data/Parameter:	CO _{2,biogenic}
Data unit:	Tonne

Description:	Amount of CO_2 that originated from biomass or DAC.
Source of data:	Invoices; monitoring and reporting regulations of the European Union Emission Trading System (EUR-Lex - 02018R2066-20210101 - EN) or equivalent; on-site measurements.
Measurement procedures (if any):	-
QA/QC procedures:	-
Monitoring frequency:	For all the CO_2 which is used for the carbonation process.
Any comment:	The methodology applies only when the sequestered CO_2 originates from biomass or DAC. If this is not the case, CO_2 removal cannot be claimed under this methodology.

Parameter ID	19
Data/Parameter:	Sink _{CaCO3}
Data unit:	Tonne
Description:	Amount of calcium carbonate (CaCO ₃) produced from indirect carbonation process that used filler material in the construction sector or in other applications that ensure the permanent storage of CO_2 .
Source of data:	Invoices, records.
Measurement procedures (if any):	-
QA/QC procedures:	-
Monitoring frequency:	For all the CaCO ₃ produced with the indirect mineral carbonation process during the monitoring period y .
Any comment:	If there is no verification of the type of application of the $CaCO_3$, the storage of the CO_2 is assumed to be non-permanent by default and no VERs are issued for the sequestered CO_2 .

Data/Parameter:	End use of mineral waste.
Data unit:	-
Description:	The end use of mineral waste carbonated during monitoring period.
.Source of data:	Any of the following, by order of preference:
	a. End use declarations
	b. Sales invoices or records
	c. Other valid sources
Measurement procedures (if any):	When end use declarations are adopted as the source of data, the following details shall be included: (i) quantity of material in mass or volume, (ii) monitoring period, (iii) specific purpose(s), and (iv) signature of operating partner.
QA/QC procedures:	-
Monitoring frequency:	The project developer shall assess the end uses of mineral waste produced by the project/activity (i.e., use in road construction, concrete structures, residential and commercial landscaping) and disclose it in the Monitoring Report.
Any comment:	The VVB shall, based on its sectorial expertise and means of verification, assess the ability of reported end use types in regard to ensuring CO ₂ permanence and provide its opinion in the Verification Report. The Certification Body shall review the information provided by the project developer and the VVB's opinion and act accordingly.

Parameter ID	21
Data/Parameter:	Renewability of biomass _{n,ff,y}
Data unit:	None.
Description:	Renewability of biomass of type n fermented at biomass fermentation facility ff in year y .
Source of data:	Biomass fermentation facility records.
Measurement procedures (if any):	Operating records from the biomass fermentation facility (e.g., purchasing invoices, sourcing agreements with growers, registration records, or supply agreements with the fermentation facility or fermentation products) which indicate the type and source of biomass used at the facility during the monitoring period.

	Renewability of biomass shall be ascertained following one of the following options:	
	Option 1. At validation and each verification, provision of suitable evidence confirming the registration or certification of the biomass fermentation facility(ies) or fermentation product(s) under jurisdictional or host country standards, regulations, or programmes which promote the use of energy from renewable sources and define eligible sources of biomass inputs. For example, the U.S. Environmental Protection Agency <u>Renewable Fuel</u> <u>Standard</u> , the <u>European Union Renewable Energy Directive II</u> , <u>Brazilian Biofuel Policy (RenovaBio)</u> , and <u>Canada Clean Fuel <u>Regulations</u>.</u>	
	Option 2. During validation and at each verification, provision of suitable evidence to GS-VVBs that biomass used at the biomass fermentation facility(ies) during the monitoring period complies with both the criteria for the definition of renewable biomass provided in <u>CDM EB 23 Report Annex 18</u> and any applicable laws and regulations.	
QA/QC procedures:	-	
Monitoring frequency:	At each verification, following reconciliation of types and sources of biomass used during the monitoring period.	
Any comment:	Fermentation facilities.	

7.3 | General Requirements for Sampling

7.3.1 | The methodology does not prescribe sampling methods for data monitoring.

8| APPLICATION TO PROGRAMME OF ACTIVITIES

8.1.1 | The methodology may be applied for standalone projects or a PoA. In the latter case, the technology provider(s) may act as CME. For inclusion of a VPA to the PoA, the inclusion criteria shall be designed following the methodology requirements and other applicable Gold Standard requirements.

ANNEX 1. SUPPLEMENTARY INFORMATION

Calcination and Carbonation Process

Calcination and carbonation reactions are involved in some industry activities, such as cement production. Cement is produced in a rotary kiln at high temperatures of 1400 to 1500° C. CaCO₃ is converted into CaO by calcination (i.e., high-temperature burning of the mineral raw material [CaCO₃]). As a result, CO₂ is separated and released into the atmosphere. The following formula describes the chemical process of calcination:

$$CaCO_3 \subseteq CaO + CO_2$$
 Eq. 1

When concrete is produced from cement, the CaO present in the cement hardens by adding water via an exothermic reaction to form calcium hydroxide and calcium silicate hydrate (C-S-H).

$$CaO + H_2O \leftrightarrows Ca(OH)_2$$
 Eq. 2

Once the concrete is hardened, the calcium hydroxide $(Ca(OH)_2)$ formed in formula Eq. 20 can again react with CO_2 to form the $CaCO_3$ occurring in formula Eq. 21, provided that the salt $CaCO_3$ exhibits the lowest solubility of all salts in the $H_2O - CO_2$ – Ca system. This process is called "carbonation":

$$Ca(OH)_2 + CO_2 \leftrightarrows CaCO_3 + H_2O$$
Eq. 3

Normally, this happens only on the surface of the hardened concrete components over the typical lifetime of 80 years. An experimental field study conducted at the Federal Swiss Institute of Technology in Zurich concluded that around 4% of the process emissions are bound over the lifetime of a concrete infrastructure.⁸

However, this process can be accelerated and increased with the direct and indirect mineral carbonation. The mineral carbonation processes use higher CO_2 concentrations than average atmospheric values of 400 parts per million (ppm), humidity, temperature, solvents, and optimised particle size of the concrete to accelerate the process of carbonation. This is where the proposed technologies and project activities can be applied.

Carbonation can similarly be employed with other types of mineral waste, such as slags and ashes. These are enriched in alkaline metal oxides, including CaO, MgO, and FeO, which consequently can result in a larger variability of carbonate composition [(x,Ca,Mg,Fe)CO₃]. Moreover, carbonation of other reactive mineral wastes can bring additional environmental benefits that can help prevent soil pollution upon disposal in landfills. An example is the carbonation of slags, in which the reaction enables the immobilisation of heavy metals within the mineral structure of carbonates.⁹

 ⁸ Birolini, L. (2019). CO₂ capture in concrete recycling residues. Master Thesis, 1–47.
 ⁹ Xu & Yi (2022). Treatment of ladle furnace slag by carbonation: CO₂ sequestration, heavy metal immobilisation, and strength enhancement. Chemosphere 287(3), 132274.

Carbonation is an exothermic process that releases heat. The reverse reaction, calcination, requires a lot of energy. Unless the CaCO₃ is exposed to temperatures above 300°C or 900°C (depending on the carbonate mineral formed), the CO₂ is durably stored in both processes. If the emissions along the value chain of the CO₂ mineralisation are smaller than the amount of CO₂ stored, these processes can facilitate net CO₂ removals. The projects thus act as geological sinks.

Technologies

In the scope of this methodology, three technologies are described. However, this methodology may also apply to future systems, which fall into the same category and where the presented calculation and measurement methods can be applied.

a. Direct Mineral Carbonation

Direct mineral carbonation sequesters carbon in reactive mineral waste that is obtained as residue or byproduct of established industrial activities. Through the applied process, solid mineral waste is exposed directly to a gas stream exhibiting an increased CO_2 concentration (>400 ppm) in a reactor system (carbonation plant) at controlled pressure. The alkaline cation oxides contained in the mineral waste, e.g. the Ca(OH)₂ and C-S-H contained in the hardened cement paste, react with the CO₂ to form chemically stable carbonate minerals, i.e., (x,Ca,Mg,Fe)CO₃. The product of this process is carbonated mineral waste.

b. Direct Slurry Mineral Carbonation

Slurry carbonation consists of an induced direct mineralisation method, in which the suspended mineral solid waste in aqueous medium reacts with injected CO_2 to precipitate carbonate minerals. Mineral carbonation processes use higher CO₂ concentrations than average atmospheric values of approximately 400 ppm and optimised CO₂ to slurry ratios to accelerate the overall process. In the slurry water, the alkaline metal oxide and hydroxide species contained in the waste materials are in a liquid-solid equilibrium with the aqueous phase. This means that the water gets enriched in alkalis and divalent metal ions. As CO₂ is absorbed by the solution, it speciates to carbonate and bicarbonate ions. Since alkaline divalent ions and carbonate ions cannot coexist in an aqueous solution, (x,Ca,Mg,Fe)CO₃ carbonate precipitates, and minimal CO_2 remains in the aqueous phase. At the end of the process, the carbonated slurry is either directly reused as in the baseline scenario (e.q., concrete wastewater in Switzerland) or the solids are filtered out and disposed of or reused for the same finality as defined in the baseline scenarios of each waste material. Depending on the type of slurry, the residual water is reused in the carbonation process (circulating in closed system) or used for other operational uses defined in the baseline scenario.

Different slurry carbonation plant geometries are possible, depending on the type of slurry mineral waste. Using the example of the concrete wastewater slurry carbonation, the plant consists of a continuous open system wastewater circulation between the wastewater collection tank and the slurry carbonation tank. During the process, the slurry carbonation reactor is filled with gaseous CO₂ and concrete wastewater, which immediately starts precipitating carbonate minerals.

Other types of slurry mineral waste carbonation might instead operate under closed system conditions. This process is preferable when the mineral waste presents some toxicity or when the wastewater cannot be used in other process operations, for example, some wastewater after carbonation of slags and ashes. Carbonate minerals start precipitating as a product of reaction of alkaline and/or metal (hydro-)oxides and bicarbonate ions. At the end of the process, the solids in the slurry are filtered out, and the aqueous phase is transferred temporarily into another reservoir until it is reused in a new slurry carbonation cycle.

In both cases, the process technology regulates the input flow of CO_2 into the tank to optimise the absorption of CO_2 in the slurry wastewater and to avoid the formation of gas bubbles that can eventually be released into the atmosphere upon discharge in the wastewater tank.

Carbonation of slurries can bring additional environmental benefits that can help prevent soil pollution upon disposal in landfills. An example is the carbonation of slags, in which the reaction enables the immobilisation of heavy metals within the mineral structure of carbonates.⁹

c. Indirect Mineral Carbonation

In the first step, the mineral waste is suspended in a solvent in the dissolution reactor. The solvent selectively extracts the alkalis contained in the alkaline metal oxide phases in the mineral waste. In the next step, the inert materials, termed regenerated sand, are filtered out of the slurry, and the alkali-enriched solution is fed to the mineralisation reactor.

There the solution is brought into contact with CO₂, which results in the crystallisation of (x,Ca,Mg,Fe)CaCO₃. Finally, the precipitated (x,Ca,Mg,Fe)CaCO₃ is filtered out for further use. The solution is recycled into the dissolution reactor. The solvent lost is compensated with a makeup stream of fresh solvent. The regenerated sand can be used as a replacement for sand in concrete in road construction or can be landfilled. Depending on the carbonate composition, there are different potential applications for the produced (x,Ca,Mg,Fe)CaCO₃, such as filler material in cement or concrete. It also can be used in the food industry or as an additive in cleansing material.

ANNEX 2: LIST OF POSSIBLE BASELINE SCENARIOS

The baseline alternatives are divided into those related to the use and provenance of CO_2 and those related to the sink activities, which shall include the following.

- A. Regarding the use/provenance of CO₂, the following baseline scenarios are possible:
 - a. Landfilling of biomass, combustion of landfill gas without capture, and storage of the CO_2 emissions.
 - b. Anaerobic digestion of biomass, cleansing of the biogas through biogas upgrading, and releasing of the separated CO_2 into the atmosphere.
 - c. Incineration of biomass without capture and storage of the \mbox{CO}_2 emissions.
 - d. Fermentation of biomass for production of bioethanol with release of \mbox{CO}_2 into the atmosphere.
 - e. Fermentation of biomass for production of bioethanol, with capture and liquefaction of CO_2 for food or other industrial purposes with temporary CO_2 storage.
 - f. Anaerobic digestion of biomass, cleansing of the biogas through biogas upgrading, and storing of the separated biogenic CO_2 in mineral waste (proposed project activity which is realised without GS4GG certification consideration).
 - g. Fermentation of biomass for production of bioethanol, with capture and liquefaction of CO_2 for sequestration in mineral waste (proposed project activity which is realised without GS4GG certification consideration).
 - h. Combustion of landfill gas, capture and separation of the emitted CO₂ with subsequent storage in mineral waste (proposed project activity which is realised without GS4GG certification consideration).
 - i. Incineration of biomass, capture and separation of the emitted CO_2 with subsequent storage in mineral waste (proposed project activity which is realised without GS4GG certification consideration).
 - j. DAC with subsequent storage of the CO₂ in mineral waste (proposed project activity which is realised without GS4GG certification consideration).
- B. Regarding the project activities at sink plants, four major types are predicted by this methodology derived from different industrial activities, thus having different baseline scenarios:
 - Demolition concrete: This is derived from the deconstruction of buildings and infrastructure during demolition activities. Possible baseline scenarios are:
 - i. Landfilling the demolished concrete without any prior treatment.
 - ii. Crushing and sorting out the steel reinforcements bars and other useful materials from demolition concrete at sorting plants with further landfilling of concrete.

- iii. Crushing and sorting out the materials from demolition concrete with further recycling into new concrete (through crushing it into concrete aggregate and using it in the preparation of new concrete or in unbound form (e.g., construction of roads).
- b. Construction wastewater: This can be divided into two subcategories:
 - i. Concrete wastewater originates when washing concrete plant equipment, such as concrete mixing trucks, upon their return from construction sites. The concrete wastewater mainly contains sand, gravel, and hydrated cement species.
 - Gravel wastewater is generated at gravel plants by mineral scrubbing of rocks. It consists of clays that adhere to sand and gravel during crushing and that are considered contaminants. Thus, they are cleaned thoroughly to ensure the high quality of gravel.
- c. Different baseline scenarios are possible for the construction wastewater: 10,11
 - i. Sand and coarse solids are recovered and used in the production of new concrete used as filling material in road construction, used in landscaping, or landfilled. A dewatered filter cake is then obtained by sedimentation or with a filter press system, and the water is pumped back into the system. The filter cake can either be disposed of in landfills or reused in the production of concrete as replacement of aggregates.
 - ii. Alternatively, for the concrete wastewater: Sand and coarse aggregates are recovered. Both aggregates and the residual concrete slurry wastewater are used in the mixing process of new concrete.
- d. Slags: Ferrous slags are a direct byproduct of iron and steel manufacturing. Slags contain highly reactive Ca and Mg species as well as heavy metals and therefore have limited application. Possible baseline scenarios include:¹²
 - i. Slags are recovered and disposed of in landfills.

¹⁰ Lanfranconi, I. (2021). Lab-scale investigation of a concrete slurry carbonation process. BSc Thesis, ETH Zürich.

¹¹ Piazza, Ernesto. "luzern: neues geschäftsfeld dank «abfall» in eschenbach". Luzerner zeitung, 20 October 2017, <u>https://www.luzernerzeitung.ch/zentralschweiz/luzern/luzern-neues-geschaeftsfeld-dank-abfall-in-eschenbach-ld.95001</u>.

¹² EUROSLAG: The European Association representing metallurgical slag producers and processors. 24 May 2023, <u>https://www.euroslag.com/applications/</u>,¹³ Wolfgang et al. (2020). Inventory of MSWI Fly Ash in Switzerland: Heavy Metal Recovery Potential and Their Properties for Acid Leaching. *Processes* 8(12): 1668.

- ii. Slags are recovered and used in construction as replacement of clinker (after its production) in cement or as aggregates.
- e. Ashes: These are a byproduct and waste material of waste incineration and/or thermal energy production. They include ashes produced by incineration of, for example, municipal waste, dried sewage sludge after wastewater treatment, or paper at the end of its life cycle. Other materials, such as cement kiln dust, a byproduct of cement production, and wood ashes also can be considered suitable mineral waste materials for direct or indirect carbonation. Baseline scenarios include:
 - i. Waste is incinerated, and ashes are disposed of in landfills or backfills.
 - ii. Waste is incinerated, and ashes are used in construction as replacement of clinker (after its production) in cement and aggregates.
 - iii. Alternatively, for ashes from municipal waste incineration¹³ and waste wood incineration:¹⁴ Ash is processed for recovery and recycling of metals, and residual inert materials are landfilled.

Version	Date	Description
2.0	28.05.2025	Revised version to include baseline carbonation, validation of project sink calculations, and scope expansion of eligible mineral waste streams.
1.0	07.03.2022	First version

DOCUMENT HISTORY

¹³ Wolfgang et al. (2020). Inventory of MSWI Fly Ash in Switzerland: Heavy Metal Recovery Potential and Their Properties for Acid Leaching. *Processes* 8(12): 1668.

¹⁴ Wolffers et al. (2021). Waste Wood Fly Ash Treatment in Switzerland: Effects of Co-Processing with Fly Ash from Municipal Solid Waste on Cr(VI) Reduction and Heavy Metal Recovery. Processes 9(1): 146.