

# White Paper: Equatic's Measurement, Reporting, and Verification Methodology

**August 2023**

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*White Paper: Equatic's Measurement, Reporting, and Verification Methodology was written in August 2023 in consultation with EcoEngineers. Concurrent with the preparation of this white paper, EcoEngineers is preparing the Equatic MRV methodology, drafted in alignment with ISO 14064-2:2019, that provides rules for eligibility, means of quantification, monitoring instructions, reporting requirements, and verification parameters for projects generating carbon removal credits using the Equatic seawater electrolysis process.*

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## o. Executive Summary

This white paper presents carbon removal company Equatic's process for removing carbon dioxide (CO<sub>2</sub>) from the atmosphere by means of seawater electrolysis. It describes how CO<sub>2</sub> is trapped as aqueous (bi) carbonate ions or within mineral solids, how net carbon dioxide removal (CDR) is rigorously quantified and verified, and why this represents permanent storage. Equatic's approach is scalable, having demonstrated its ability to mitigate ongoing and accelerating climate change through exacting measurement, reporting, and verification (MRV) protocols and procedures.

### The Equatic process for trapping CO<sub>2</sub>

Equatic's technology is a transformative electrolytic approach for CDR that makes use of the ocean-air equilibrium of CO<sub>2</sub> and the enormous abundance of alkaline cations (Mg<sup>2+</sup>, Ca<sup>2+</sup>) in seawater. Equatic takes advantage of these intrinsic attributes during a continuous process to trap and permanently store CO<sub>2</sub> within aqueous (bi)carbonates and solid carbonates. Electrochemical stimulation yields: (1) Cathode: locally produced alkalinity which results in CaCO<sub>3</sub> and Mg(OH)<sub>2</sub> precipitation, while producing H<sub>2</sub>(g) – a clean fuel, and (2) Anode: locally produced acidity which is consumed to rapidly dissolve alkaline solids and restore the alkalinity of the seawater effluent. The absorption of atmospheric CO<sub>2</sub> into Mg(OH)<sub>2</sub>-equilibrated and decarbonated seawater within the boundaries of the plant enables straightforward MRV of atmospheric CDR.

### How Equatic quantifies and verifies net CO<sub>2</sub> removal

The Equatic process is intentionally designed and engineered to implement and measure CDR within a closed system. The compositions of the influent stream, the retained solids, and the effluent stream are measured. The direct, in-plant measurements of the rate and extent of CDR provide continuous, unambiguous data about operational performance. The net extent of CDR effected by the process is quantified as follows:

$$\text{Total Carbon Removal}_{\text{CO}_2\text{e}} = \text{Drawdown}_{\text{CO}_2\text{e}} - \text{Emissions}_{\text{CO}_2\text{e}}$$

**Drawdown**<sub>CO<sub>2</sub>e</sub> is the sum of the total dissolved CO<sub>2</sub>e and the total solid CO<sub>2</sub>e sourced from the atmosphere that is permanently stored. Equatic quantifies the amount of CDR effected within the plant by using multiple on-stream, and real-time sensors and additional, off-line sensors to provide measurement redundancy and certainty.

**Emissions**<sub>CO<sub>2</sub>e</sub> includes the net embodied CO<sub>2</sub> emissions from material and energy use (e.g., the grid emissions factor of electricity, and the amount of energy embodied in the co-produced hydrogen assuming typical purification demands and conversion efficiencies).

Data records of the above measurements, including metered readings from on-line, on-stream sensors, are provided to an independent third party to monitor and verify net CDR.

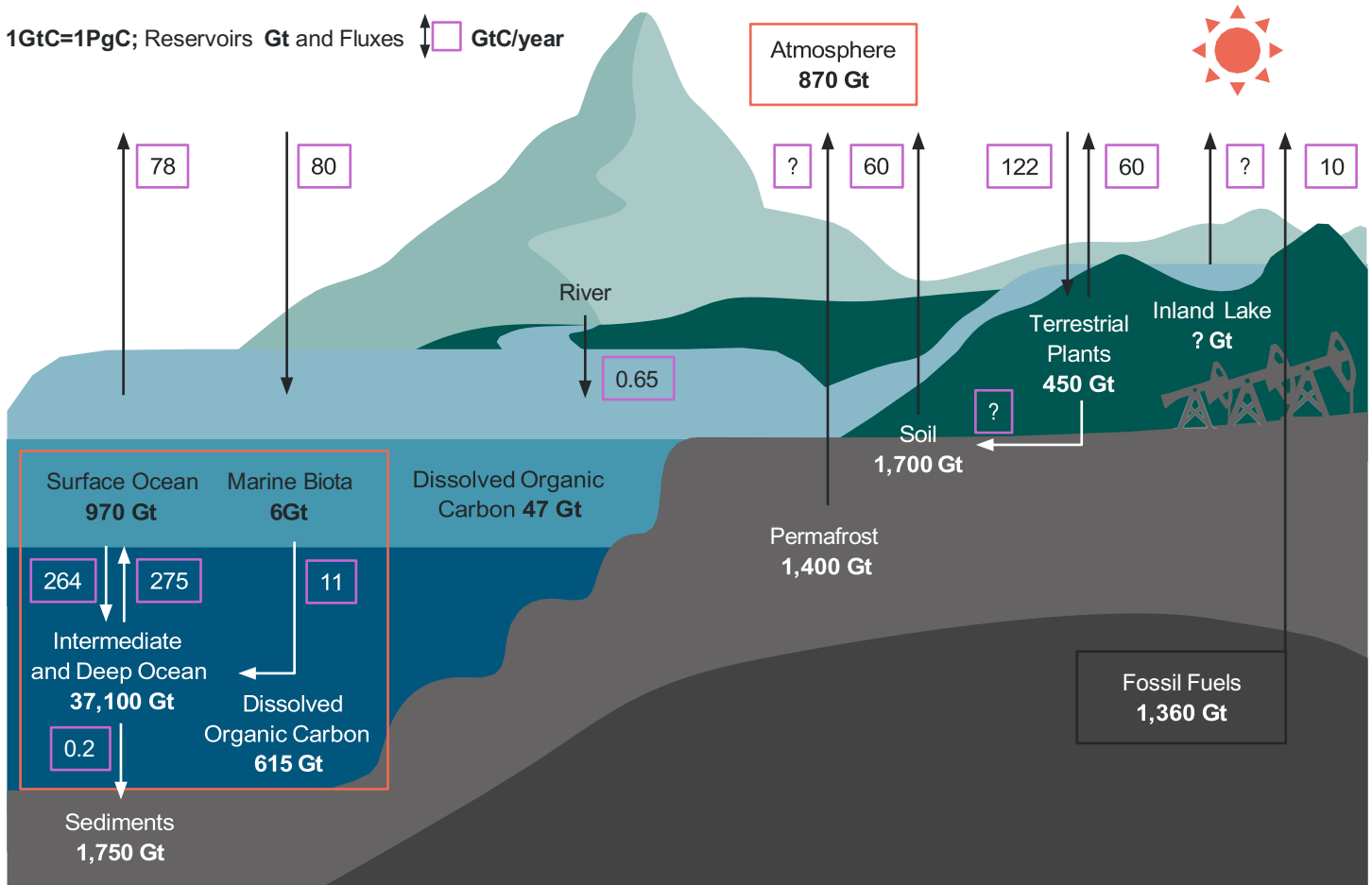
### Why Equatic's net CO<sub>2</sub> removal represents functionally permanent carbon storage

The production of aqueous bicarbonates immobilizes carbon dioxide for more than 10,000 years.<sup>1,2,3</sup>

The production of solid carbonates immobilizes carbon dioxide for up to billions of years.<sup>4,5</sup>

## 1. The Global Carbon Cycle and Seawater-Mediated Carbon Dioxide Removal

The distribution of carbon in the Earth system is not static. Carbon moves between and across different storage reservoirs and the ocean plays a central role in carbon cycling. **Figure 1** shows the distribution and the net flows between different storage reservoirs.



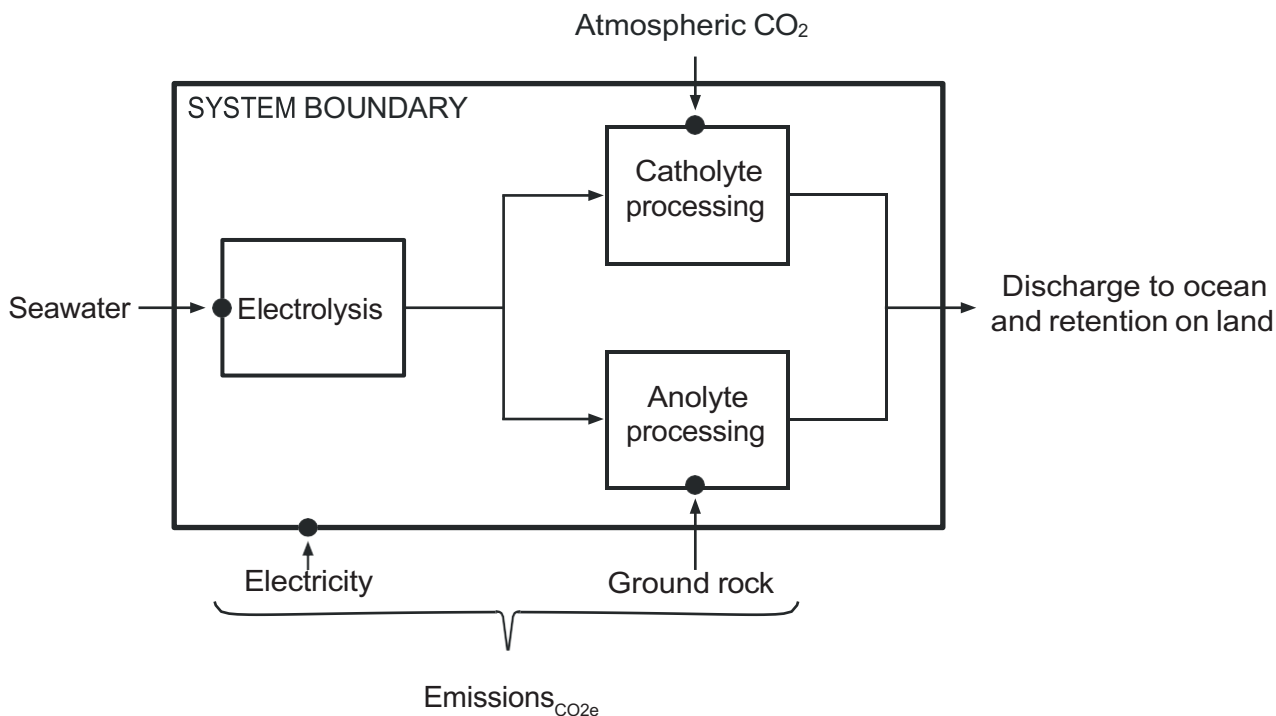
**Figure 1: Global Carbon Cycle**

The oceans absorb and immobilize atmospherically derived  $\text{CO}_2$  in the form of dissolved carbon species (i.e., predominantly  $\text{HCO}_3^-$  at a prevailing pH of  $\sim 8.1$ )<sup>6</sup>, a highly durable form of carbon storage. This cycle results in 25% of all anthropogenic  $\text{CO}_2$  emissions ( $\sim 9 \text{ GtCO}_2$ , i.e.,  $1 \text{ g C} = 3.664 \text{ g CO}_2$ ) being removed from the atmosphere by the oceans annually.<sup>7</sup> Given the prevailing chemistry<sup>8</sup> and ongoing ocean acidification, the innate capacity of the oceans to absorb additional  $\text{CO}_2$  from the atmosphere is decreasing. The dissolved  $\text{CO}_2$  content in seawater is controlled by the seawater's pH, salinity, the atmospheric partial pressure of  $\text{CO}_2$  ( $p\text{CO}_2$ ), and the temperature as described by Henry's law. Equatic makes use of these relationships, and the immense capacity of seawater to store  $\text{CO}_2$ , to ensure measurable, verifiable, and permanent CDR.

## 2. System and Project Boundary

A life-cycle analysis (LCA) of the Equatic process, in accordance with ISO standards, will assess the net CDR. The LCA establishes the system and temporal boundaries to determine the net flows of mass, energy, and embodied and operational emissions in terms of  $\text{CO}_2\text{e}$  to operate the Equatic plant.

The system boundaries are shown in **Figure 2**. Inside the system boundaries are the Equatic plant, including the electrolysis process, catholyte and anolyte processing circuits, and all ongoing and corresponding activities that Equatic performs for the purposes of CDR.



**Figure 2: Equatic's system boundary with four key inputs (seawater, electricity, rock, air)**

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The temporal boundaries concern the time over which the Equatic process creates CDR credits. The process starts at the time seawater enters the Equatic plant and ends with the ocean discharge of effluent and/or retention of mineral carbonate solids on land. This is a continuous process, notwithstanding the need for plant maintenance that may require partial or full shut-down. Over any given interval, the change in the amount and distributions of carbon species within the system boundaries, and the net energy utilized to cause this change, will provide a direct measure of net CDR. Further details of the method of quantification are provided in Sections 4 and 5.

An LCA, conducted with respect to the above-stated boundaries, will therefore include measuring **Drawdown**<sub>CO<sub>2</sub>e</sub> and the following **Emissions**<sub>CO<sub>2</sub>e</sub> activities to achieve CDR:

- Operating and maintaining the electrolyzer and balance of plant

The electricity consumed to operate and maintain the plant may be associated with CO<sub>2</sub> emissions. The grid emissions factor characterizes the average CO<sub>2</sub> emitted per unit of electricity generated for a given grid. Energy used by the plant is calculated based on measurements from the main power meters and encompasses total power consumption from electrolyzers, pumps, blowers, control and measurement instruments, and general plant energy use.

- Grinding rock (e.g., milling, if applicable)

Energy consumed by grinding rock is estimated using the Bond Work Index (BWI) and verified by, where available, rock crushing energy consumption and fuel use data. This calculates the energy required to reduce particle sizes, for which a location-specific CO<sub>2</sub> grid emissions factor is applied. Not all rocks will require grinding. For example, it is expected that tailings from mining operations or rock dust from quarry operations are appropriate for use as is, reducing energy needs substantially.

- Transporting ground rock to the plant

Energy consumed in transporting rock to the Equatic plant will be aggregated on a mass averaged distance. A location- and mode-specific emissions factor is used to calculate the CO<sub>2</sub> emitted per tonne of rock transported.

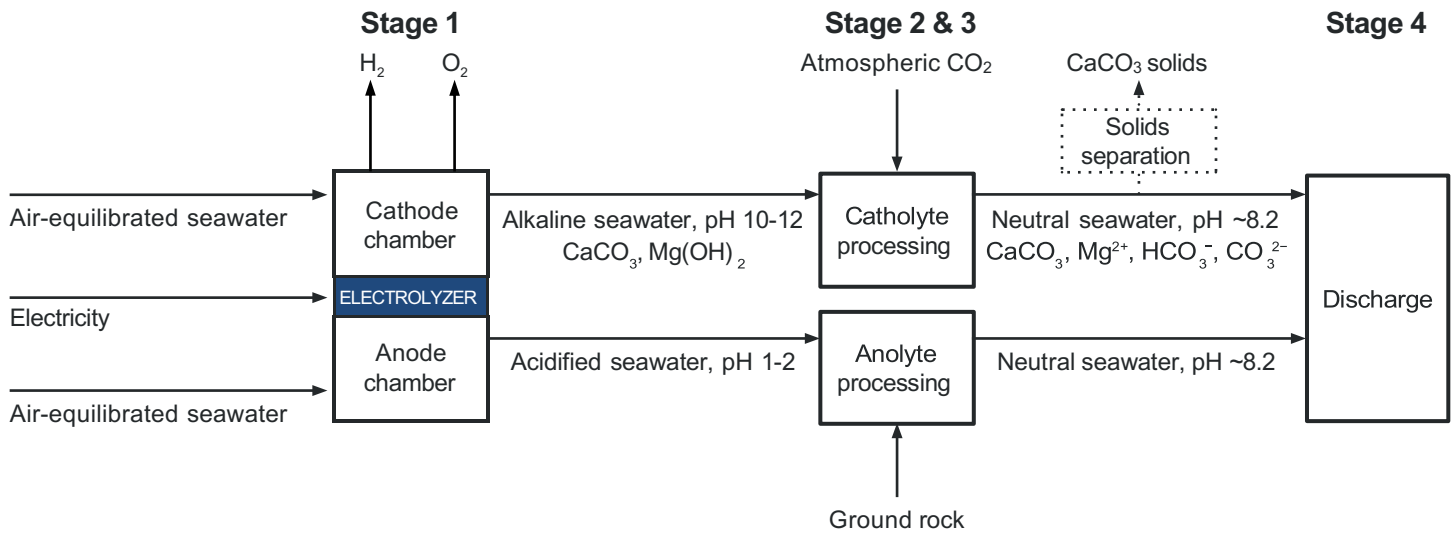
- Building Equatic's CDR plant

The raw materials and equipment used in the fabrication, assembly, and construction of the plant are associated with CO<sub>2</sub> emissions. If those CO<sub>2</sub> emissions are significant, an emissions factor is applied. To determine significance, total lifetime **Emissions**<sub>CO<sub>2</sub>e</sub> are projected over twenty years and, where the corresponding total CO<sub>2</sub>e from materials and construction exceeds 1% of total lifetime **Emissions**<sub>CO<sub>2</sub>e</sub>, the CO<sub>2</sub>e from materials and construction are included.

### 3. The Equatic Process

There are four stages in the Equatic process (**Figure 3**). By measuring the change in the amounts and distributions of carbon species between the influent (the baseline), the retained solids, and the effluent (together, the amount of CDR), Equatic will establish the **Drawdown**<sub>CO<sub>2</sub>e</sub>.

These four stages are described below. Appendix A has further detail on the chemistry of Stages 1-3.



**Figure 3: Equatic's CDR process**

#### Stage 1: Electrolysis

Seawater flows through an electrolyzer. By applying an electrical current, (i) pH increases at the cathode and divalent cations precipitate as the minerals Mg(OH)<sub>2</sub> (brucite or magnesium hydroxide) and CaCO<sub>3</sub> (calcium carbonate), and hydrogen gas is evolved, and (ii) pH decreases at the anode and oxygen gas is evolved. The two streams, catholyte (alkaline) and anolyte (acidic), flow out from the electrolyzer to be separately processed. It should be noted that the use of proprietary electrodes prevents the production of chlorine species (ions, gas).

#### Stage 2: Catholyte Processing

The Equatic process bubbles atmospheric air through the CaCO<sub>3</sub>/Ca<sup>2+</sup>/Mg(OH)<sub>2</sub> catholyte stream. The (i) dissolution of Mg(OH)<sub>2</sub> in seawater in the presence of CO<sub>2</sub> in air (pCO<sub>2</sub> = -3.38 atm, equivalent to 420 μatm) immobilizes atmospherically derived CO<sub>2</sub> in the form of dissolved inorganic carbon species (HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>2-</sup>), while (ii) the reaction of the remaining Ca<sup>2+</sup> ions with newly dissolved CO<sub>2</sub> precipitates additional CaCO<sub>3</sub>. The CaCO<sub>3</sub> that is present from Stage 1 remains unaffected. If desired, the CaCO<sub>3</sub> solids can be separated following catholyte processing.

### Stage 3: Anolyte Processing

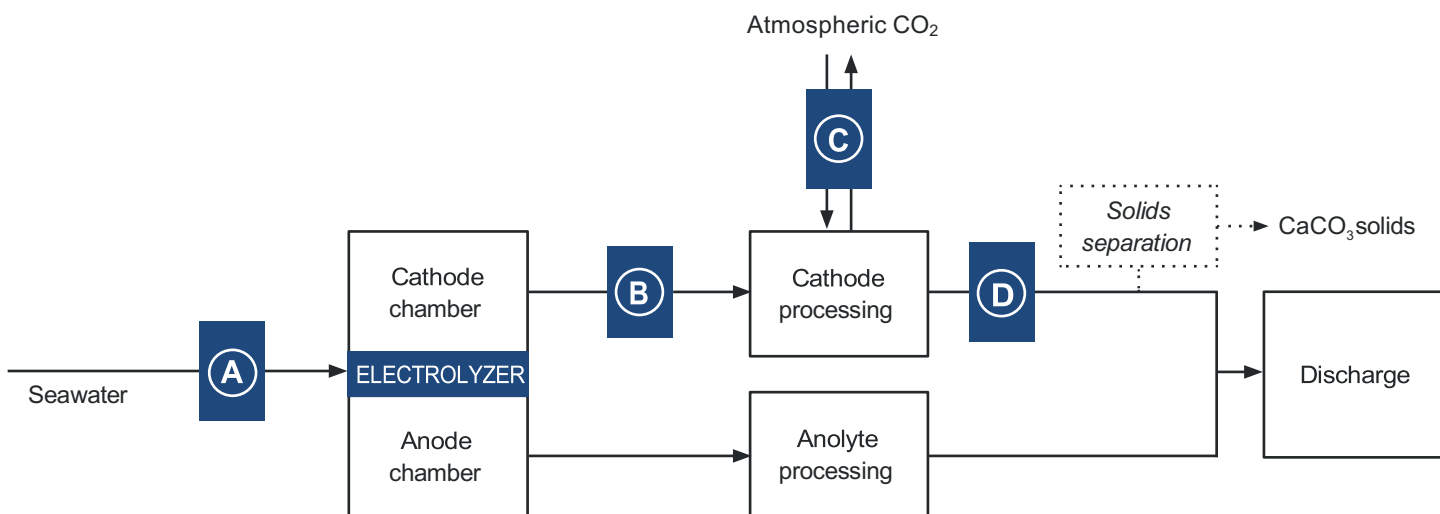
To avoid discharging acidic seawater into the ocean, the anolyte stream is neutralized. Crushed rock is contacted with the anolyte within a dissolution circuit. This replenishes the divalent cations and returns the pH level of the anolyte stream to that of the seawater influent. Suitable widely available and naturally occurring rock types are mafic and ultramafic. Stage 3 occurs concurrently with Stage 2.

### Stage 4: Discharge

The processed catholyte and anolyte seawater streams are returned to the ocean.

## 4. Measurement

The Equatic process is intentionally designed and engineered to measure CDR within a closed system. The compositions of the influent stream, the retained solids, and the effluent stream are measured. The direct, in-plant, on-line and on-stream measurements of the rate and extent of CDR provide continuous, unambiguous data about operational performance. **Figure 4** presents the high-level locations of the different sensors used for calculating  $\text{Drawdown}_{\text{CO}_2\text{e}}$ . These sensors are a subset of the sensors used for overall plant operation and monitoring/sampling for compliance with environmental regulations.



**Figure 4: On-line, on-stream sensors for measuring CDR within the Equatic process**

#### Liquid Phase Analysis: Point A, Point B, and Point D

Equatic has an array of sensors to measure CO<sub>2</sub> drawdown within the boundaries of the plant. This avoids the need for open ocean measurements to determine the amount of CDR. Simply put, the chemical composition of the seawater inflow is compared to the chemical composition of the seawater outflow.



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Meter readings at Points A, B and D are used. Three independent validation approaches can be deployed to ensure precision and accuracy of **Drawdown**<sub>CO<sub>2</sub>e</sub> measurements. Appendix A provides additional detail on the pathways.

#### Dissolved CDR Validation #1

The difference in dissolved inorganic carbon (DIC) between Point A and Point D is a direct measure of the increase in aqueous bicarbonate species ( $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ). Therefore, the change in DIC measures the carbon dioxide trapped within the dissolved (bi)carbonate species prior to discharge to the ocean.

#### Dissolved CDR Validation #2

Once magnesium ions are completely removed from seawater (via  $\text{Mg}(\text{OH})_2$  formation) in Stage 1, and once those magnesium ions are restored after the catholyte stream undergoes carbonation in Stage 2, then:

$\text{Mg}^{2+}$  concentration at Point A =  $\text{Mg}^{2+}$  concentration at Point D

$\text{Mg}^{2+}$  concentration at Point B = 0

Similarly, when calcium ions are completely removed from the seawater (via  $\text{CaCO}_3$ ) in Stages 1 and 2, then:

$\text{Ca}^{2+}$  concentration at Point D = 0

This analysis implicitly assumes (i) a relationship between  $\text{Mg}^{2+}$  and  $\text{CO}_2$  removal of 1:1.7, and (ii) a relationship between  $\text{Ca}^{2+}$  and  $\text{CO}_2$  removal of 1:1 (see Appendix A).

In this way, a comparison of the metered readings at Points A, B, and D will close the mass balance and provide verification for CDR.

#### Dissolved CDR Validation #3

Metered readings for alkalinity, pH, temperature, and salinity are taken at Point A, B and D. These readings are then entered into a calculation program, e.g., CO2SYS.<sup>9</sup> The CO2SYS program calculates the concentrations that describe the inorganic carbon system (carbonate ions, bicarbonate ions, dissolved  $\text{CO}_2$ ). The concentrations of the inorganic carbon species are then compared between seawater inflow and outflow.

#### **Gas Phase Analysis: Point C**

Metered readings are taken at Point C. The  $\text{CO}_2$  concentration in the air is measured twice: (1) prior to air being pumped into the carbonation reactor, and (2) after air exits the carbonation reactor. Comparing the two readings, for a given air flow rate, provides a direct measurement of the amount of  $\text{CO}_2$  converted into bicarbonate ions.

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### Solid Phase Analysis: Point B and Point D

A sample is collected from a slipstream and sent to the laboratory for the determination of mineral phase distributions using thermal gravimetric analysis (TGA) and x-ray diffraction (XRD). TGA and XRD provide mass percentages of the mineral composition and water content in the solids. Samples are collected weekly during initial plant commissioning and then monthly during regular operations to verify that the mineral phase composition has not changed.

The amount of CO<sub>2</sub> sequestered resulting from the formation of each mineral phase is calculated by multiplying the total mass of the mineral by its molecular weight (MW) and the appropriate CDR Factor. The total CO<sub>2</sub> sequestered in the solids is a summation of all the CO<sub>2</sub> contained within each of the mineral solids.

$$\text{CO}_2 \text{ Mineral (g)} = \text{Total Mass of mineral (g)} * \text{MW} * \text{CDR Factor} * (\text{MW CO}_2)$$

The CDR Factor is 1 for CaCO<sub>3</sub> (i.e., 1 mol CO<sub>2</sub> per mol CaCO<sub>3</sub>) and 1.7 for Mg(OH)<sub>2</sub> (i.e., 1.7 mol CO<sub>2</sub> per mol Mg(OH)<sub>2</sub>) (see Appendix A).

### Solids Separation

If desired, CaCO<sub>3</sub> can be separated after catholyte processing. The total weight of CaCO<sub>3</sub> produced is determined when the solids are shipped and weighed by scale. The record of weight is documented on the bill of landing. The weight of water, as determined by the mass percentages from TGA and XRD performed in the Solid Phase Analysis, is subtracted from the total weight of solids to validate CDR as follows:

$$\text{Total Mass of CaCO}_3 \text{ (g)} = \text{Mass\%CaCO}_3 \text{ (g/g)} * [\text{Mass of Total Solids (g)} - \text{Mass of Water(g)}]$$

### Data management

Rigorous quality assurance and control procedures ensure reliable and accurate data collection and reporting. Measurements will be stored on a cloud-based server, accessible through web-based software by authorized project team members. Secure, view-only access of necessary data will be provided for audit and assurance by third parties, including auditors and external carbon credit verifiers.

### Measurements for EIA

In addition to measurements taken for **Drawdown**<sub>CO<sub>2e</sub></sub>, the Equatic process includes monitoring/sampling to meet regulatory requirements. Process design elements coupled with rigorous monitoring will ensure that the effluent complies with local environmental guidelines and regulations for safe discharge.

## 5. Permanence

Equatic is committed to permanent CDR. Permanent storage is necessary to ensure that the carbon dioxide removed from oceanic and atmospheric sources is not released back into the atmosphere. Equatic stores

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carbon dioxide in the form of solid carbonates and aqueous bicarbonate ions. Solid carbonates immobilize carbon dioxide for billions of years<sup>4,5</sup> and aqueous bicarbonates immobilize carbon dioxide for >10,000 years.<sup>1,2,3</sup>

The solid calcium carbonate produced by Equatic can be (i) discharged back into the ocean, where it will remain stable because of seawater's supersaturation with respect to mineral carbonates (e.g., seashells in the ocean), or (ii) beneficially utilized, e.g., within construction materials. Mineral carbonates, to be destabilized, would have to be exposed to temperatures greater than several hundred degrees Celsius, or to strong acid environments (pH<5).

Finally, the Equatic process ensures permanence because it directly counteracts ocean degassing. The increase in seawater alkalinity arising from  $\text{Mg}(\text{OH})_2$  dissolution more than compensates for any degassing arising from decreasing atmospheric  $\text{CO}_2$  concentrations associated with large-scale and ongoing carbon dioxide removal.

## 6. Reversal

The Equatic process ensures permanent carbon dioxide storage in the form solid carbonates and aqueous bicarbonate ions. There is no risk of reversal from the primary pathways of immobilization. Equatic has considered additional secondary pathways for the release of  $\text{CO}_2$  outside of the system boundary:

1. Reversal risk due to discharge of un-neutralized acidic anolyte. To counter  $\text{CO}_2$  degassing from acidification (i.e., related to the shift of the solution-phase carbonate equilibrium towards  $\text{CO}_{2(g)}$ ), the alkalinity of the anolyte effluent will be replenished by the dissolution of alkaline solids including mafic and ultramafic rocks, i.e., to elevate the concentrations of divalent cations. This engineered solution replenishes the alkalinity of the anolyte effluent to ensure that there is no net  $\text{CO}_2$  release/reversal risk.
2. Reversal risk caused by secondary carbonate (aragonite) precipitation resulting from alkalinity (i.e.,  $\text{Mg}(\text{OH})_2$  dissolution). The  $\text{CO}_2$  equilibration of  $\text{Mg}(\text{OH})_2$ -containing seawater within the plant significantly decreases the discharge pH and therefore, the risk of localized secondary carbonate precipitation. For context, the critical saturation ratio,  $\Omega$ , for runaway aragonite precipitation is 5 ( $\text{SI} = 0.69$ )<sup>10</sup>. Using a model that considers ocean circulation, i.e., ECCO (Estimating the Circulation and Climate of the Ocean) LLC270 physical fields,<sup>11</sup> and constraints of  $\Delta\text{pH} = 0.1$  and  $\Delta\Omega$  aragonite = 0.5, indicates that the near-coastal implementation of the Equatic process – around the world – could enable several gigatonnes of CDR per year without any risks of  $\text{CO}_2$  degassing.

## 7. Reporting and Verification

### Carbon Accounting

The Equatic technology will remove carbon dioxide with high certainty. Accordingly, the following governing principles for carbon accounting are in place to assure all private and public buyers of the quality of the Equatic carbon credits.

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- Consistency

Equatic will apply the same carbon accounting standards across reporting periods to ensure comparability between periods. Where it is necessary to update or change a standard, Equatic will fully disclose the change and provide the rationale for making the change.

- Prudence

Equatic will use fact-based data and not speculative estimates to generate carbon credits. The amount of carbon dioxide removed, Drawdown CO<sub>2e</sub>, will be quantified directly and unambiguously by sensors within the boundary of the plant. **Emissions**<sub>CO<sub>2e</sub></sub> will be based on actual recorded energy usage (e.g., in the case of electricity) and, where available, energy usage in the processing and transport of rock.

- Transparency

Equatic will publish project documentation depicting the total amount of CDR, a registry and a database of Equatic's carbon credits that have been produced and retired, and Equatic's MRV methodology.

- Matching

Equatic will match **Drawdown**<sub>CO<sub>2e</sub></sub> with **Emissions**<sub>CO<sub>2e</sub></sub> for the reporting period. Where a source of **Emissions**<sub>CO<sub>2e</sub></sub> extends over more than one reporting period, Equatic will apportion the corresponding CO<sub>2e</sub> based on its use or consumption within the system boundary in the applicable period.

- Conservativeness

Equatic will ensure the conservativeness of reporting with reference to the choice of approaches, assumptions, methods, parameters, data sources and key factors used in the carbon accounting.

## Verification

An independent expert will confirm that the Equatic process, as operationalized within a project boundary, conforms to the MRV methodology. This is to ensure that the accounting of CDR activities is carried out in accordance with an ISO-standard methodology. This will be supplemented by internal monitoring, verification, and risk management procedures to maintain adherence to the methodology.

An independent auditor will verify the total amount of CDR. The auditor will determine whether the reported **Emissions**<sub>CO<sub>2e</sub></sub> and **Drawdown**<sub>CO<sub>2e</sub></sub> are verifiable by reviewing the following for each reporting period:

- Activities conducted within the system boundary;

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- Data generated directly by the Equatic plant operations (sensors, meters, sampling);
  - Documentation of inputs that are used within the system boundary;
  - Evidence of retiring credits; and
  - Record keeping and internal operating policy adherence.

In the first reporting period post-commissioning, the tonnage of CDR by Equatic will be audited to verify additionality versus a base case (the 'counterfactual'). Project activity of this nature is essentially non-existent commercially, and without financing it would not occur. Thus, the counterfactual is that the project does not proceed. Each Equatic plant will be subject to a pre-feasibility and investment review. This review will establish the grounds for proceeding with the project activity, including the expected revenues and funding returns. Any sources of public funding will be considered in determining project additionality.

### **Environmental reporting**

Equatic is committed to high environmental standards. An Environmental Impact Assessment (EIA) will be prepared for each project. The EIA will identify the discharge characteristics and levels, monitoring requirements and the reporting cadence specific to the jurisdiction and site that the project will operate in. Ongoing reporting will be performed to ensure that Equatic continues to satisfy the applicable regulatory requirements.

## **8. Conclusion**

The world faces two unprecedented challenges: reducing its reliance on fossil fuels and removing legacy CO<sub>2</sub> emissions. Equatic addresses both challenges by electrolyzing seawater. This leads to CDR from the atmosphere by immobilizing CO<sub>2</sub> as aqueous bicarbonates and solid carbonates. This also leads to the production of carbon negative hydrogen as a substitute for fossil fuels.

By design, the Equatic process features:

- Easy-to-identify CO<sub>2</sub> emitting system inputs (energy, rock, transport);
- A closed-system with direct, in-plant, on-line and on-stream measurements of the quantity of CDR; and
- A transparent reporting and verification approach to account for high quality CDR credits.

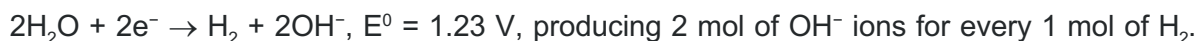
Equatic uses these design elements, in combination with the vastness of the ocean, to ensure atmospheric carbon is immobilized for at least 10,000 years.

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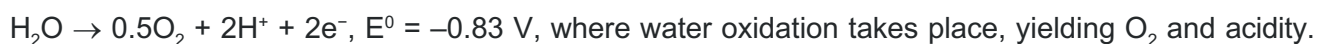
## Appendix A: Equatic Mass Balance Chemistry

### Stage 1: Electrolysis

Cathode reaction is given by:



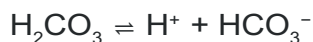
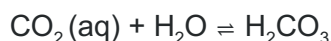
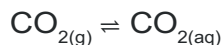
Anode reaction is given by:



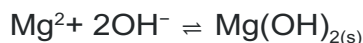
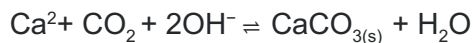
Total cell reaction is given by:



CO<sub>2</sub> dissolution and speciation in water is described by:



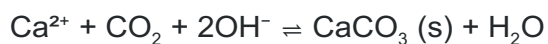
Therefore, the net chemical reactions that describe the formation of CaCO<sub>3</sub> and Mg(OH)<sub>2</sub> at the cathode are:



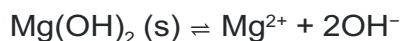
From stoichiometry, the formation of 1 mol of CaCO<sub>3</sub> captures 1 mol of CO<sub>2</sub>, while requiring 2 mol of OH<sup>-</sup>.

### Stage 2: Catholyte Processing

The net chemical reaction that describes the formation of CaCO<sub>3</sub> is:



The chemical reactions that describe the formation of HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>2-</sup> ions from Mg(OH)<sub>2</sub> dissolution are:



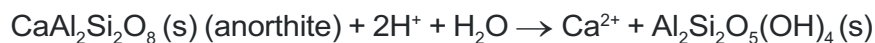
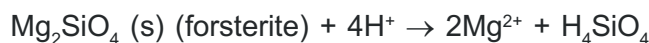
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While 2 mol of OH<sup>-</sup> are required per mol of CO<sub>2</sub> stored as CaCO<sub>3</sub> (i.e., a CO<sub>2</sub> removal efficiency of 1 mol of CO<sub>2</sub> per mol CaCO<sub>3</sub>), only 1.2 mol of OH<sup>-</sup> are required per mole of CO<sub>2</sub> stored as dissolved (bicarbonate: HCO<sub>3</sub><sup>-</sup> and carbonate: CO<sub>3</sub><sup>2-</sup>) ions (i.e., a CO<sub>2</sub> removal efficiency of 1.7 mol of CO<sub>2</sub> per mol of Mg(OH)<sub>2</sub>). This implies that it is more chemically and energy efficient to immobilize CO<sub>2</sub> in the form of dissolved aqueous carbonates, i.e., rather than mineral carbonate species.

### Stage 3: Anolyte Processing

Candidate solutes for anolyte processing include pyroxenes (e.g., augite: (Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)<sub>2</sub>O<sub>6</sub>, diopside: MgCaSi<sub>2</sub>O<sub>6</sub>) and olivines (e.g., forsterite: Mg<sub>2</sub>SiO<sub>4</sub>) that naturally occur in mafic (basalts, gabbro) and ultramafic (peridotites) rocks. The quantity of rock required to enhance the cation abundance and the pH of the anolyte effluent is a function of the solute's acid (H<sup>+</sup>, proton) neutralization capacity (ANC).

As Ca<sup>2+</sup> and Mg<sup>2+</sup> species are dissolved, the anolyte pH and total dissolved CO<sub>2</sub> content elevates as described by the following representative chemical reactions:



It is evident that an increase in the total dissolved CO<sub>2</sub>, ΣCO<sub>2</sub>, occurs only when the pH exceeds 5. Furthermore, the replenishment of the cations increases not only the pH but also the salinity, enhancing CO<sub>2</sub> absorption, e.g., a reason why seawater contains much more dissolved CO<sub>2</sub> than freshwater.

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