

Detailed Community Response

Cornwall: Discussion and Emailed Q&A on Foundational Science (2023)

Context

The following discussion and questions were posed via email to the team at Planetary thanks to the connections created via our community engagement activities in the Cornwall region. In the spirit of transparency, we have included all discussion and questions offered to us in **blue text** and our responses in **black**.

Additional information, including references to some of the foundational peer-reviewed papers on the scientific basis for ocean alkalinity enhancement, is available on our site's <u>Additional Resources section</u>.

Note

One of the main claims made by the writer is that the Planetary process of ocean alkalinity enhancement would not remove carbon dioxide from the atmosphere.

A peer-reviewed paper ('<u>Seawater alkalinity enhancement with magnesium hydroxide and its</u> <u>implication for carbon dioxide removal</u>) was recently published (well after we had received the questions on this page). It describes the huge potential of exactly the process that we propose (Yang, et. al, 2023): "We conservatively estimate that $44.4 \times 10^{**9}$ tonnes of CO₂ (~ 3.3 times the current annual CO₂ sink in the ocean) could be removed from the atmosphere...")

We hope the perspective taken here proves interesting to those who want to dig deeper into this topic with us.

Community Input:

Oceanic water geochemistry

Seawater is a natural alkaline, high buffering capacity system with a pH 8.2 – 8.3 range. This is due to several factors, though notably, the reaction with calcium carbonate rich rocks such as limestone, chalk, marble and calcite-bearing mineral veins, and with

magnesium-carbonate rocks such as dolomite are the dominant contribution to adding carbonate ions (CO32-) into solution as per the usual reactions:

Calcium carbonate:	$CaCO_3 \leftrightarrow Ca^{2+} + CO_3^{2-}$	(1)
Magnesium carbonate:	$CaMg(CO_3)_2 \leftrightarrow Ca^{2+} + Mg^{2+} + 2CO_3^{2-}$	(2)

The carbonate ion produced, then reacts to form the bicarbonate ion (HCO3–) as follows:

$$H^{+} + CO_3^{2^-} \leftrightarrow HCO_3^{-}$$
(3)

This is an acid-consuming reaction that raises the pH of the solution in full saturation to pH 8.3. This is why the pH of seawater has stabilized over millennia to this pH range. Bicarbonate ions serve as a buffering capacity, with the ability to consume more acidity (H+) if it is added to the system.

Oceanic acidification due to atmospheric carbon dioxide emissions

Acidification of seawater occurs due to the reaction of atmospheric carbon dioxide (CO_2) with water in a 2-step reaction as follows:

$$CO_2 + H_2O \leftrightarrow H_2CO_3$$
 at $pH < 6.3$ (4)

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^- \qquad at \, pH > 6.3 \tag{5}$$

Carbonic acid (H_2CO_3) is formed from the reaction of gaseous atmospheric CO_2 with H_2O . However, the presence of carbonic acid in seawater is in fact very low, due to the dominant pH in seawater of pH 8.2 – 8.3. At this alkaline pH, seawater actually serves as a buffering system to carbonic acid, due to bicarbonate release from terrestrial rock weathering of carbonates, and due to the dissociation of carbonic acid at this pH range. Therefore, at seawater pH > 6.3, the major species of the inorganic form of CO_2 is the bicarbonate ion HCO_3^- due to the dissociation of carbonic acid.



Figure 1: Seawater pH plotted versus percentage HCO⁻

The oceans themselves serve as a form of neutralisation to acidification due to the buffering capabilities present due to carbonate rock dissolution, and from the dissociation of carbonic acid at this pH range.

Planetary Response:

These sections above describe the main features of seawater chemistry and the carbonate buffering system but omit some aspects that are relevant to Planetary's approach.

Reactions 4 and 5 correctly indicate that, at pH below 6.3, dissolved inorganic carbon (DIC) is predominantly present as dissolved (aqueous) CO2 and carbonic acid (H_2CO_3), while at pH above 6.3 bicarbonate takes over as the dominant species (as the equilibrium of Reaction 5 shifts to the right). This is illustrated in the more complete Bjerrum plot shown below as Figure 2, which adds the $CO_{2(aq)}$ plus H_2CO_3 (collectively denoted $H_2CO_3^*$) and CO_3^{2-} concentration lines to the HCO₃⁻ line shown in Figure 1.

Figure 2 shows that, although bicarbonate (HCO₃⁻) is the dominant form of DIC at current seawater pH, $H_2CO_3^*$ and CO_3^{2-} are also present.

For seawater at equilibrium with the atmosphere (pCO₂ = 400 µatm) and pH = 8.05, the respective concentrations are $[H_2CO_3^*] = 17 \mu mol/kg$, $[HCO_3^-] = 2043 \mu mol/kg$, and $[CO_3^{2-}] = 144 \mu mol/kg$, where concentrations are in micro-moles per kilogram of seawater (see Note 1.)

The buffering capacity of seawater is more correctly due to the presence of carbonate ions which are able to neutralize carbonic acid by accepting a proton (H^+) in the reaction;

$$H_2CO_3 + CO_3^{2^-} \leftrightarrow 2HCO_3^{-}$$
(6)

The gradual depletion of this carbonate ion concentration, or carbonate buffer, leads to ocean acidification.



Figure 2: Carbonate speciation versus pH (Bjerrum plot)

Community Input:

What component of DIC will MH react with in your calculations to remove carbon from the seawater to form a precipitate, and encourage atmospheric CO_2 drawdown? What is this precipitate? Can you please show your full geochemical reaction please?

Planetary Response:

Apologies if we have somewhere described the process as one that would "remove carbon from the seawater", as this is not correct.

The OH ion released on MH dissolution reacts with dissolved CO_2 according to the reaction given in our response (Reaction 9 below). This is the complete reaction. There is no precipitate formed. By converting $CO_{2(aq)}$ to bicarbonate the partial pressure of CO_2 dissolved in seawater is reduced, and CO_2 drawdown is driven by the resulting partial pressure gradient from the atmosphere to the ocean (see for example <u>Renforth and Henderson 2017</u>).

Community Input:

Your point of adding non-naturally occurring alkalinity to a huge oceanic system that in itself can rely on naturally occurring carbonate rocks to dissolve, how can you be so sure in the long term this will actually make any difference?

Planetary Response:

The long term supply of alkalinity to the ocean from rock weathering will indeed result in the drawdown from the atmosphere to the ocean of all anthropogenic CO_2 , but this will take place on a 10,000 to 100,000 year timescale. Ocean pH decline attests to the fact that this natural process cannot keep up with the rate at which we are adding CO_2 to the atmosphere and ocean. The proposed addition of alkalinity (derived from similar mineral sources) accelerates this process so that it can have an effect on a climate relevant timescale.

Community Input:

There are huge industries occurring to extract MH out of seawater globally. By adding MH here in St Ives Bay and other areas, is this not being offset by MH being drawn out of seawater in another part of the world? Have you taken this into account? Will your addition

not be a 'drop-in-the-ocean' compared to the amount of MH (thus alkalinity) being extracted by seawater?

Planetary Response:

Many industrial activities and processes have negative environmental (including climate) impacts, and the extraction of alkalinity from seawater is just one of these. Carbon dioxide removal (CDR) can only have an impact on climate restoration if these processes with their associated CO_2 emissions and other damaging impacts are massively reduced – preferably stopped altogether.

Our proposed addition is indeed a drop in the ocean. If it can be successfully scaled up it will provide an incremental climate benefit, but only if emissions and other such impacts are reduced to an unavoidable minimum.

Community Input:

Magnesium hydroxide and planned usage for Planetary Technologies

Planetary Tech's principal idea is to "Restore the ocean balance and sequester carbon dioxide". As explained above, the ocean already has a natural balance at doing this process itself, and any carbon dioxide added, usually dissociates to form bicarbonate – as it is already a buffering system.

To add an extra buffer in the form of magnesium hydroxide, will do little to no effect on the already high-buffering capability of the oceanic system. The geochemical idea (of Planetary Tech) is that the addition of magnesium hydroxide (Mg(OH)2) will react with carbonic acid (H2CO3) in seawater, creating a precipitation of magnesium carbonate (MgCO3) as per the usual stochiometric reaction:

$$Mg(OH)_2 + H_2CO_3 \rightarrow MgCO_3 + H_2O \tag{7}$$

However, two things inhibit this reaction. The first is that carbonic acid (H2CO3) does not exist in solution of a seawater pH range of pH 8.2 -8.3 (see Figure 1), and secondly, magnesium carbonate is already super-saturated in seawater at a concentration of 600 mg L-1 due to the dissolution of naturally occurring magnesium carbonate-rich rocks, such as

dolomite. Therefore, the ability of magnesium hydroxide to interact with carbonic acid and form this product are negligible.

Planetary Response:

The uptake by the ocean of roughly 25% of our historical CO_2 emissions has significantly reduced the ocean's inherent buffering capacity (see NOAA 2019), resulting in a drop in pH from the long term equilibrium of 8.2 over many millions of years to around 8.05 today (see NOAA 2020). The addition of alkalinity to the ocean raises pH and shifts the equilibrium point in Figure 2 to the right, reducing $[H_2CO_3^*]$ and increasing $[HCO_3^-]$ and $[CO_3^{2-}]$. This is the way in which Planetary's approach restores ocean chemistry – by locally restoring pH back towards its historical equilibrium. This shift in carbonate system equilibrium is a well-established fact of ocean chemistry (see for example Zeebe and Wolf-Gladrow, 2001.)

The addition of magnesium hydroxide (MH) does not result in the precipitation of magnesium carbonate (MgCO₃). Precipitation can only occur when the saturation state (Ω_{MgCO3}) exceeds 1. The saturation state is defined as

$$\Omega_{MgCO3} = [Mg^{2+}] [CO_3^{2-}] / K_{sp}$$
(8)

where the terms in square brackets are the ion concentrations and Ksp, the solubility product of MgCO3, is equal to 10-7.8 (Bénézeth et al., 2011). Taking $[CO_3^{2^-}] = 144 \ \mu mol/kg = 8.64 \ mg/kg$ from the example above gives $[Mg^{2^+}] = 1830 \ mg/kg$ at $\Omega_{MgCO3} = 1$. In seawater $[Mg^{2^+}]$ is typically around 1300 ppm (1300 mg/kg; see <u>Wikipedia: Seawater</u>), which means that $[Mg^{2^+}]$ would have to be increased by around 40% (530 mg/kg) before precipitation could occur. This can never be achieved by the dissolution of MH since MH solubility is in the order of 6 mg/kg.

The reaction of MH with carbonic acid ($H_2CO_3^*$) in the questions (Reaction 7) is incomplete, the full reaction is:

$$Mg^{2+} + 2OH^{-} + 1.65(CO_{2ag}) \rightarrow Mg^{2+} + 1.48(HCO_{3}^{-}) + 0.17(CO_{3}^{2-}] + other ions$$
 (9)

where Mg^{2+} and $2OH^{-}$ are the ions released as MH dissolves, and the stoichiometric coefficients are for seawater conditions of pH = 8.1, salinity = 35 ppt, temperature = 20°C, and pressure = 1 bar.

The assertion that "carbonic acid (H_2CO_3) does not exist in solution of a seawater pH range of pH 8.2 – 8.3" is incorrect. As noted above and shown in Figure 2, although the bicarbonate ion is dominant all three species exist in varying proportions across the full pH range relevant for ocean conditions. Addition of MH will further reduce the carbonic acid concentration (as pH increases) and increase the carbonate ion concentration, helping to restore the ocean's natural buffering capacity.

Community Input:

If you are so sure of these calculations, why are you conducting such an intensive monitoring routine after the addition?

Planetary Response:

Monitoring is an essential part of the MRV (Monitoring, Reporting and Verification) process that will ultimately verify the CO₂ removal achieved. For this particular CDR approach, numerical ocean models will be central to that verification, and the physical and chemical monitoring results will be used to calibrate and validate these models. In terms of ecological monitoring, although current understanding is that the addition will be entirely benign in the marine environment, local monitoring and confirmation is clearly required in order to validate our assumptions.

Community Input:

An addition to the alkaline pH of seawater means that the dominant species of the aqueous CO_2 form present that will react with magnesium hydroxide is the bicarbonate ion (HCO₃⁻). The reaction of magnesium hydroxide will follow the reaction:

 $Mg(OH)_2 + 2HCO_3^- \rightarrow Mg(HCO_3)_2$

(10)

The product of this reaction is magnesium bicarbonate. Furthermore, the addition of magnesium hydroxide will consume naturally occurring bicarbonate ions (HCO_3^{-}) and will lower the natural buffering capacity of the oceans. Magnesium bicarbonate is very soluble in seawater and a very bioavailable form of magnesium to organic biota. This is not what Planetary Tech has assumed. Full comprehensive studies therefore have to be conducted to examine the impact of magnesium bicarbonate on organic species in the bay before an application is made.

The aforementioned has assumed that magnesium hydroxide will actually fully dissolve or interact with bicarbonate ions in seawater. In actual fact, in a seawater pH of 8.2, the ability of magnesium hydroxide to enter solution is very low. The very low solubility is expressed as 12 mg L⁻¹. The majority of the magnesium hydroxide will form suspended solid particles that will fall down onto the seafloor as a deposit. However, seawater contains very abundant concentrations of dissolved magnesium Mg²⁺ (1300ppm), being the 4th most dissolved cation in solution in seawater. Due to the common ion effect, the solubility of magnesium hydroxide will be lowered, due to the prevalence of Mg²⁺ cations in solution. Due to this effect, it is more likely that in seawater, magnesium hydroxide is most likely to dissociate into the magnesium cation (Mg²⁺) and the hydroxyl ion (OH⁻), instead of forming bonds with the bicarbonate ion (HCO3⁻) in the following reaction:

$$Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^{-}$$
(11)

The effect of this reaction is that in the immediate area of discharge, the pH may increase to up to pH 10.35. This by far exceeds the natural pH of any terrestrial environment on Earth, and would have countless hazardous effects on the wildlife of the bay, and on the potential remobilization of attenuated metal species in the underlying sediment – present due to the deposition from acid mine drainage discharge from surrounding mining and smelter waste in the region. This of course would have to be studied and analysed, but a geochemical potential hazard exists from the application of magnesium hydroxide, especially into an estuarine environment that has a known contamination issue of historic mine and smelting waste and metal contamination.

Planetary Response:

Reaction 10 is incorrect; the acid-base reaction is between MH and carbonic acid, producing not consuming bicarbonate ions. The end product is indeed largely Mg^{2+} and HCO_3^{-} (the two ions released when magnesium bicarbonate dissolves in seawater.)

The statement that "magnesium bicarbonate is very soluble in seawater and a very bioavailable form of magnesium to organic biota" is correct, but the assertion that "this is not what Planetary Tech has assumed" is not. As noted, these two ions are already extremely abundant in the ocean and are therefore already bioavailable. Published studies (Gim et al., 2018) show that the ocean's dissolved inorganic carbon (DIC) would need to increase by a factor of 4.5 for the increased bicarbonate concentration to be problematic for marine organisms. As a benchmark, drawdown into the ocean of all CO_2 in the atmosphere (in other words, moving and storing the entire atmospheric CO_2 inventory into the ocean as DIC), would increase the average DIC in the ocean by around 2%.

A pH of around 10.4 is indeed possible for a saturated solution of MH in freshwater, with a more limited peak pH of around 9.5 for a saturated solution in seawater. The Environmental Agency (EA) permissible range for discharges to the sea is from pH 6.5 to 8.5 after initial dilution with seawater in a mixing zone around the discharge location. Modeling work commissioned by Planetary (using the industry standard methods required by the EA) indicates an initial dilution factor of between 450 and 2700 across the 14-day tidal cycle so that, even if a pH of 10.4 was reached within the wastewater discharge pipeline, the pH increase at the edge of the mixing zone after dilution with seawater (at an assumed pH of 8.1) would not exceed 0.001.

Note that the wastewater discharge is not into an estuarine environment. The discharge point is located approximately 2 km off Godrevy Point, and the discharge plume will be predominantly carried up and down the coast by the tidal currents (see below), although some alkalized water, with pH elevated above the seawater background by an immeasurably small amount, will be circulated into St lves Bay by tidal eddies (Figure 3).

Community Input:

Location and chemical discharge impact area

Considering the type of discharge that Planetary Tech envisions, whether that is a point discharge in pre-existing sewage/wastewater discharge points within the harbor limit of Hayle Estuary or Godrevy, or whether that is a surface discharge in the bay, what is certain is the possibility to calculate the volume of water that would be affected.



Figure 3 : Simulated movement of a parcel of water from the discharge location off Godrevy Point over a 5-day period

Assuming a discharge of 200 t of pure $Mg(OH)_2$, and assuming the company achieves their envisioned 100% dissolution of the material into terrestrial seawater, $Mg(OH)_2$ will have a saturation constant (Ksp) of 0.00122g/100ml in seawater, which equates to 12 mg L⁻¹ when total saturation will occur. Calculating the total volume of water that will be affected equates to:

(12)

 $\frac{200\ 000\ 000\ g\ Mg(OH)2}{0.0122\ g\ Ksp} = 16\ 393\ 442\ 622\ L\ H_2O\ affected$

Extrapolated to a volume assuming full saturation of magnesium hydroxide in seawater, 16 393 000 m³ of water will be affected by this discharge. If the water depth is 1 m, then a 4.05 km² footprint would occur. If we assumed a closed system in respect to zero water mixing influences, such as tidal mixing, terrestrial rainwater and river water mixing, and assuming a mean water depth of 4 m in the inshore area at Hayle Estuary, this would equate to a 1.05 km² surface footprint area (I) over the bay of St Ives Bay.

This is illustrated on the map below (Figure 4) in the inshore area off Hayle Bar. However, if discharge occurs at sea, with a mean water depth of 15 m in the bay, then a footprint area of 0.27 km^2 (II) would occur. Either way, a huge volume of water will be affected by this 200 t forecast discharge.

However, water dispersion and natural processes such as tides would cause further dispersion of the effected discharge and the likelihood of a much further dispersion footprint than that illustrated in Figure 4.



Figure 4: Surface to seafloor seawater area footprint affected based on a 200 t discharge of $Mg(OH)_2$

Planetary Response:

For clarity the discharge will be from the pre-existing wastewater discharge point off Godrevy Point. No discharge will take place within the Hayle harbor limit, within the Hayle Estuary, or in the bay.

As noted, dilution is indeed very important. The large volume of water that will be affected by the MH addition is the reason why the changes that occur over this volume will be immeasurably small. The total alkalized seawater volume will be substantially greater than the 16.4 million m³ calculated in the questions, as a result of mixing and dispersion by tidal flows and residual currents. Modeling work commissioned by Planetary indicates that over the course of one year (which is roughly the timescale for CO² exchange from the atmosphere) the alkalized water will be carried NE up the coast of Cornwall, Devon, and Somerset to the vicinity of Lundy Island, before being carried NW across the Bristol Channel towards the Pembrokeshire coast (see Figure 5). Starting in a water depth of 20 m at the discharge point, the affected water depth will gradually increase to around 100 m after one year, with the alkalized seawater plume eventually tracing out a sea surface area of around 1500 km².

Assuming an average 50 m water depth across the 1-year footprint equates to a water volume of some 75 billion m^3 of water. Dissolution of 200 tonnes of MH in just the first 10% of this volume would increase the total seawater alkalinity by 0.45 µmol/kg or roughly 0.2%.



Figure 5 : Simulated movement of a parcel of water from the discharge location off Godrevy Point over a 1-year period

Community Input:

Magnesium interaction with inorganic acids

The only acid that the company has assumed magnesium hydroxide will interact with is carbonic acid. However, many more acids will exist in the estuary, especially because two rivers drain into the area and tidal pools such as Copperhouse Creek and Carnsew Pool are present. Additionally, other freshwater systems drain into the bay, once of which has a significant acid mine drainage influence, entering the bay at Godrevy, aptly named the Red

River, and at one time, was the most contaminated river in Europe. The dominant acid from mine drainage is sulphuric acid (H_2SO_4). The most dominant acid from terrestrial rainwater is nitric acid (HNO_3), which would also occur in sewage wastewater, as would phosphoric acid (H_3PO_4). The following reactions will take place when an addition of magnesium hydroxide takes place.

$$Mg(OH)_2 + H_2SO_4 \rightarrow MgSO_4 + 2H_2O$$
(13)

 $Mg(OH)_2 + 2HNO_3 \rightarrow Mg(NO_3)_2 + 2H_2O$ (14)

 $3Mg(OH)_2 + 2H_3PO_4 \rightarrow Mg_3(PO_4)_2 + 6H_2O$ (15)

Magnesium nitrate $(Mg(NO_3)_2)$, magnesium sulphate $(MgSO_4)$, and magnesium phosphate $(Mg_3(PO_4)_2)$ are the products that will be released when magnesium hydroxide is exposed to nitric, sulphuric and phosphoric acids respectively. None of these reactions remove carbon from the water.

Planetary Response:

Planetary has considered the potential for MH to react with other acids, although these reactions are unlikely to consume a significant fraction of the added alkalinity. pH measurements performed by PML Applications at the Godrevy outfall in September 2022 ranged from 7.96 to 8.02, suggesting a moderate freshwater influence when compared with typical UK continental shelf seawater pH values of 8.05 (winter) to 8.1 (summer). The extreme range from 7.96 to 8.10 represents an excess [H⁺] concentration of 3.0 10-9, equivalent to 0.165 μ mol/kg of excess acid content, roughly 1% of the 17 μ mol/kg carbonic acid concentration from the example quoted above. While consumption of added alkalinity by reaction with these acids would not result in CO2 drawdown, it would nevertheless have a beneficial effect in countering ocean acidification.

The pH of the wastewater effluent, as measured by PML at the treatment works in September 2022, ranged from 7.2 to 7.6, largely due to the very high concentration of biogenic CO_2 originating in the aerobic treatment process. Analysis performed by PML Applications found the following concentrations; $[CO2(aq)] = 920 \mu mol/kg$, $[NO_3^-] = 283 \mu mol/kg$, $[PO_4^{3-}] = 36 \mu mol/kg$. After dilution across a tidal cycle the nitrate and phosphate concentrations would also be roughly 1% of the ambient seawater carbonic acid concentration.

Community Input:

I appreciate your baseline organic acids assumption, but SWW has a long history of sewage discharge in high rainfall precipitation events. As your rate release is staggered over many months, can you not guarantee organic acid concentrations will increase at times when this occurs, increasing your calculated 1 % of nitrate and phosphate concentrations to carbonic acid concentration?

Planetary Response:

Agreed that if the organic acid content in the effluent were to increase under certain circumstances then the consumption of alkalinity without CDR benefit would also increase. We believe the potential impact of this is likely small; we will be monitoring for large rain events and the potential of overflow.

Community Input:

From your calculations, biogenic CO_2 resulting from the treatment works was expressed as 920 µmol/kg. Would this biogenic CO_2 not react with the MH addition, removing carbon, but not from seawater but from terrestrial water, and hence, not have time to react with what the desired reaction will be in the oceans? And this biogenic CO_2 is not directly linked to CO_2 derived directly from the atmosphere, but from human waste, soil etc.

Planetary Response:

Yes, this is correct, removal of biogenic CO_2 from the wastewater effluent was clearly demonstrated in the September 2022 methods test. This also has a climate benefit because it prevents the release of this CO_2 to the atmosphere when the effluent reaches and equilibrates with the ocean.

Community Input:

Regarding Total Carbon Footprint and Carbon Removal as per the "Cornwall Community Engagement" document, please could we have calculations of how much gCO₂e/kg will be removed per tonne of MH addition and how you ascertained this value?

Planetary Response:

Roughly 1.25 tCO_2/tMH , depending on precise seawater conditions (T, S). Derivation of this can be found in the MRV protocol on Planetary's website.

Community Input:

When calculating Carbon Footprint, have you considered:

- I. Secondary contractor party involvement?
- II. Continued monitoring from offshore boats?
- III. Personal travel (air) Canada to/from the UK?
- IV. Manufacture of all equipment used for distribution and monitoring?
- V. Personal travel to and from site locations?

Planetary Response:

Yes, we have considered these items. Our Life Cycle Assessment (LCA) emissions approach is discussed in the Cornwall FAQ, and can also be found in the MRV protocol document on the Planetary website. We include a factor for "hidden carbon footprints" and that value will be set in conjunction with our verifier Isometric.

Community Input:

Was the MH sourced from mine waste from an asbestos mine in Quebec? How was it processed into pure MH (Brucite)? Can you provide trace element analyses of the material you are using? Are there any trace metal constituents you are aware of and how will this impact the geochemistry of seawater in St Ives Bay?

Planetary Response:

This topic is covered in the Cornwall FAQ. MH to be used in the Hayle trial will be from a natural brucite mineral deposit. Trace element analysis has been conducted as part of the product selection process and will be repeated on each batch used to confirm compliance with the EA EQS requirements at the planned dosing rates. To increase transparency, we will publish this information during the proposed trial, as it becomes available.

Notes

1) Precise concentrations depend on seawater salinity and temperature, as well as a number of other parameters. The XL based CO2SYS (<u>Pierrot et al. 2006</u>) is a useful tool to investigate the seawater carbonate system, including the impact of alkalinity addition.

References

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Additional information, including references to some of the foundational peer-reviewed papers on the scientific basis for ocean alkalinity enhancement, is <u>available here</u>.