Pre-Trial Audit of the Planetary and South West Water Ocean Alkalinity Enhancement Pilot

Report Reference: UC17253 v8.0
February 2024

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V1.0	Draft toxicology assessment issued to client for comment.	SC	CV	22/08/2023
V2.0	Draft Carbon Sequestration Review issued to client for comment.	SA	CV	01/09/2023
V3.0	Draft Hydroxide Dispersion Modelling (Coastal Mixing) issued to client for comments.	SA	CV	07/09/2023
V4.0	Draft including magnesium hydroxide audit and WwTW permit and process issued to client for comments.	SC	CV	18/09/2023
V5.0	Draft final report issued to client for comment.	SC	AJ	09/11/2023
V6.0	Draft final report updated following EA and Planetary comments.	AJ	AJ	15/01/2024
V7.0	Draft final report – minor updates following discussion with EA.	AJ	AJ	18/01/2024
V8.0	Final report.	AJ	SH	06/02/2024

This document has been produced by WRc.

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Glossary

AA	Annual Average
ADCP	Acoustic Doppler Current Profiler
AF	Assessment Factor
CDR	Carbon Dioxide Removal
CO_2	Carbon Dioxide
CLP	Classification, Labelling and Packaging
D-WAQ	Water quality module within the Delft3D model
DIC	Dissolved Inorganic Carbon
DR	Dissolution rates
E(L)C50	Effect/Lethal Concentration. The concentration at which 50% effect/mortality is observed compared to the control
EQS	Environmental Quality Standards
HW	High Water
Kd	Sediment-water partition coefficient
LCA	Lifecycle Assessment
LW	Low Water
MAC	Maximum Allowable Concentration
MH	Magnesium Hydroxide
Mole	Unit of measurement for quantity of chemical species
MRV	Measurement, Reporting and Verification
NOEC	No observed Effect Concentration
OAE	Ocean Alkalinity Enhancement
PBT	Persistent, Bioaccumulative, and Toxic
pCO_2	Partial pressure of CO_2
PE	Peak Ebb
PEC	Predicted Environmental Concentration
PF	Peak Flow
PNEC	Predicted No-Effect Concentration
REACH	Registration, evaluation, authorisation, and restriction of chemicals
SS	Suspended Solids
STW	Sewage Treatment Works
TGD	Technical Guidance Document

TA	Total Alkalinity
WFD	Water Framework Directive
WRc	Water Research Centre
WwTW	Wastewater Treatment Works

Summary

i Background and objectives

Planetary and South West Water plan to introduce magnesium hydroxide into the final effluent pipe at Hayle Wastewater Treatment Works (WwTW) during a 90-day trial that primarily aims to study the safety and efficacy of OAE (Ocean Alkalinity Enhancement) with the possibility of sequestering carbon in a deployment that could come in the future. The Environment Agency (EA) has a responsibility to ensure that the planned trial will have no adverse environmental impacts and that robust controls are in place before and during the trial, giving confidence to all stakeholders.

The Water Research Centre (WRc) has been commissioned by the EA to undertake a desk-based pre-trial audit. This will assess information provided by Planetary and South West Water with the aim of ensuring that the EA's requirements for the trial are met. The pre-trial audit will review Planetary's plans to minimise and monitor environmental impact, review the carbon sequestration calculations, and aim to ensure that potential impacts at the WwTW are adequately considered.

ii Audit findings

Magnesium hydroxide audit

The magnesium hydroxide audit looked at two areas, the manufacturing quality and the social responsibility of the sourcing.

Regarding manufacturing quality, there is no traceability of the material from the mine and along its transport, milling and storage journey. There is also no confirmation of exactly at what stage the samples were tested as other contaminates may have been introduced at the milling stage if there was no quality control. It is recommended that the brucite currently in Southampton is tested again (using the same test parameters as completed previously) in the UK by a laboratory accredited to ISO 17025:2017 with samples taken randomly (i.e., not from the top) of the storage sacks.

Regarding social responsibility, while sourcing from China may not always carry high risks, due to the health and safety risks associated with mining, and the lack of available data on company governance, sourcing from China is not recommended without 'on the ground' due diligence. Other risks, such as environmental, are also present in the region, with little evidence to demonstrate the likelihood or severity of their presence within this supply chain. WRc would not recommend that Planetary use the same source of brucite in the future, unless comprehensive auditing was undertaken to better understand the level of risk, and check it is within a reasonable level.

WwTW permit and process audit

The addition of magnesium hydroxide at Hayle WwTW takes place after the final effluent system and therefore does not affect the performance of the treatment plant. The impact of the dosing near to the discharge point in the bay is not expected to increase the suspended solids (transparency of the treated sewage) by more than a few milligrams per litre. This is a small increase compared to the suspended solids concentration permitted in the final effluent.

The dissolution process (the interaction of seawater with dissolved magnesium hydroxide) is complex. The Planetary model includes the effects of pH but not of temperature. pH has a greater effect on the dissolution rate than temperature does, with dissolution decreasing as pH increases. The effect of ignoring the temperature effect reduces the dissolution rate at lower temperatures, which results in a lower pH because of the reduced concentrations of dissolved magnesium hydroxide. The lower pH then results in an increase in the dissolution rate. The effect of ignoring the temperature effect on dissolution rate is therefore unclear, because of the interaction with the pH effect, where low pH increases dissolution, low temperature reduced dissolution, and low dissolution results in lower pH values. It is therefore not clear if the impact of the dissolution rate is over-stated, and further studies to include temperature are recommended.

Magnesium hydroxide dispersion modelling audit

The marine dispersion models used for this investigation, Delft2D and CORMIX, are appropriate and have been built following recognised and accepted methodologies and data. The hydrodynamic model (Delft2D) has not been calibrated against any field data, although Acoustic Doppler Current Profiler (ADCP) data have been used to compare and verify against the results. The model performs reasonably well against the ADCP data but tends to overpredict ebb flows.

CORMIX was used to determine how the discharge should be modelled in the hydrodynamic model. CORMIX is a relatively simple mixing model and its output is used to confirm the plume extent and mixing within a water column in the near- and mid-field areas of the outfall. The CORMIX results confirmed that the discharge, with its tendency to rise to the surface and become almost fully mixed at the mid-field (~50 m from the outfall), could be represented adequately by assuming it would be fully mixed within one grid cell in the hydrodynamic model with its current grid resolution.

It is noted that the hydrodynamic model tends to overpredict the ebb flows, as shown when compared to those from the ADCP data, and this would over predict the effects of dispersion and mixing. This may have implications for the water quality and dispersion modelling, although the modelling report suggests that this is not likely to be the case.

Environmental toxicology assessment

Planetary developed an Environmental Quality Standards (EQS) screening tool to compare metal concentrations at various dosing rates assuming average effluent flow rates and 100% dissolution of metals (which is highly unlikely and therefore overly conservative).. The subsequent dilution of the effluent by the receiving ocean would significantly bring the individual concentrations of the metals below their respective EQS, even at times of lowest dilution by the ocean. Therefore, adverse effects on the marine organisms are not anticipated following exposure to the metals. This has been based on the results of the magnesium hydroxide sample analysis provided by Planetary which, as mentioned in Section 2, were not fully auditable.

Magnesium hydroxide (MH) is of low acute toxicity to aquatic organisms and of low chronic toxicity to microalgae. The concentration of magnesium hydroxide below which adverse effects on marine organisms will most likely not occur (predicted no effect concentration, PNEC) derived by Planetary or WRc is highly conservative due to the relatively high uncertainty factors used to ensure protection of aquatic life because of the limited data available on its toxicity. Therefore, the ratio of the predicted environmental concentrations (PEC) of MH and its PNEC suggests a potential risk to marine water. However, the physico-chemical properties of MH, its breakdown pathway and the fact that magnesium ions are ubiquitous in the natural environment, support that MH poses a low risk to the aquatic environment. Furthermore, this PNEC assessment is open for revision, since it is very likely that magnesium hydroxide actually poses a lower risk to marine organisms than the PNEC currently suggests. Taking all aspects into account (length of proposed trial, dosing concentrations, etc), it is likely that the risk to marine organisms from MH in this trial is very low. The availability of long-term data on fish, crustaceans and other marine species would lead to the use of a lower uncertainty factor in the PNEC calculation, and thus a higher PNEC and the resulting risk would be lower. Although the generation of additional chronic toxicity data on fish, crustacean and at least two other marine species would refine the PNEC, it could be challenging to achieve due to the difficulties in maintaining a stable concentration in water for the entire length of the toxicity test required to generate chronic data.

Review of Carbon Sequestration Calculations

Carbon dioxide removal (CDR) efficiency is a measure of the actual amount of carbon stored long-term in comparison to the maximum amount possible for the mass of magnesium hydroxide added. Several processes can result in a CDR efficiency of less than 100%. For example, sinking of partially dissolved magnesium hydroxide or alkalinity enhanced water to the deep ocean before exchanging CO_2 with the air would reduce CDR efficiency. Increases in ocean alkalinity can encourage the chemical or biological formation of limestone (calcium carbonate), which could reduce or reverse the intended ocean uptake of carbon.

Planetary’s magnesium hydroxide dispersal modelling shows dilution and dispersion result in near undetectable changes to seawater chemistry outside the 125m mixing zone surrounding the outfall. There is a *medium* risk of calcium carbonate formation within this zone.

The proposed monitoring has measures to assess calcium carbonate formation and provides adequate coverage within the mixing zone for tracking the impacts of the project and verifying the model results at weekly intervals. An additional sampling point beyond the 125m mixing zone is recommended to verify the predicted small changes to seawater chemistry.

Planetary have stated that the modelling reviewed was not intended to represent the proposed trial, and an improved model is currently under development. The model used to assess potential CDR efficiency contains satisfactory carbonate chemistry modelling but does not currently include the effects of biology on air-sea gas exchange, adding a small amount of uncertainty to the amount of carbon being drawn into the sea. The peak proposed dosing rates are 17x higher than the modelled dosing rates. The effects on water chemistry of the proposed dosing rate would be less than 17x the modelled effects, due to the solubility of the magnesium hydroxide. It is likely that the current model underestimates CDR efficiency (it predicts efficiency of 60% in winter and 26% in summer) due to alkalinity leaving the modelled area, overpredicted ebb flows, and assumptions around dissolution rates.

A CDR efficiency of 73% or greater is required to produce a net carbon offset in this project. This threshold includes the carbon footprint of shipping the magnesium hydroxide from China, so net offset can be achieved at lower efficiencies if lower carbon sources of magnesium hydroxide are used. There is potential for significant net carbon removal from scaling this approach, likely limited by the amount of magnesium hydroxide required.

1. Introduction

1.1 Background

Planetary and Southwest Water plan to introduce magnesium hydroxide into the final effluent pipe at Hayle Wastewater Treatment Works (WwTW) during a 90-day trial that primarily aims to study the safety and efficacy of OAE (Ocean Alkalinity Enhancement) with the possibility of sequestering carbon in a deployment that could come in the future. The Environment Agency (EA) has a responsibility to ensure that the planned trial will have no adverse environmental impacts and that robust controls are in place before and during the trial, giving confidence to all stakeholders.

1.2 Scope

WRc has been commissioned by the EA to undertake a desk-based pre-trial audit. This will assess information provided by Planetary and South West Water with the aims of identifying relevant considerations for such an audit and ensuring that the EA's requirements for the trial are met. The pre-trial audit will review Planetary's plans to minimise and monitor environmental impact, review the carbon sequestration calculations, and aim to ensure that potential impacts at the WwTW are adequately considered.

1.3 Audit objectives

The audit has four main elements:

1. Review how the magnesium hydroxide has been sourced – assess whether the quality control, social responsibility and environmental safety procedures are appropriate.

2. WwTW permit compliance and process impacts – assess how Planetary and South West Water plan to ensure that existing discharge permits are not breached. Assess if any adverse impacts to treatment are likely, or if additional benefits could be realised.

3. Environmental toxicology assessment – assess likelihood of toxic effects when the magnesium hydroxide reaches St Ives Bay.

4. Review carbon sequestration calculations – confirm if the claimed carbon benefits of the project are likely to be realised and advise of any potential limitations in the carbon modelling methods proposed.

1.4 Structure of this report

This report contains one section for each aspect of the audit. Section 2 examines the magnesium hydroxide sources. Section 3 reviews the proposed dosing approach and whether the existing discharge permits at Hayle WwTW are likely to be breached. Section 4 includes a review of the suitability of the coastal mixing model used to model the impact of the discharge. Section 5 comprises the environmental toxicology assessment. Section 6 considers the carbon sequestration calculations. Section 7 provides overall conclusions from the audit along with recommendations for the trial phase, should this go ahead.

2. Magnesium hydroxide audit

This section assesses whether the quality control, social responsibility and environmental safety procedures that have been followed during the manufacture of the magnesium hydroxide (MH) are appropriate.

WRc were advised that it was not feasible to visit the MH production site(s) in China. Although this would ideally have been done, we have independently reviewed all documentation provided by Planetary and South West Water, with the aim of giving confidence that appropriate processes have been followed to ensure the quality of the MH manufacture. It must be noted that all documents provided by Planetary and South West Water have been taken in good faith.

This part of the audit will cover three areas: manufacturing; storage, transport, and quality assurance; and Environmental, Social and Governance (ESG).

2.1 Overview

Planetary sourced MH from Garrison Minerals LLC in the form of a technical grade brucite (UM10) which is mined in China. The brucite was shipped to Houston, Texas. Twenty tonnes were shipped to London, England and stored in Southampton. It would then be transported to Hayle WwTW.

Due to the nature of information available to the audit team, this audit has been developed using risk-based criteria. Risks are assessed based on their probability (likelihood) and severity (impact).

The following ratings have been allocated to each category:

Low Risk	Highly unlikely to result in a quality issue but best practice not being adhered to.
Medium Risk	Unlikely to result in a quality issue but best practice not being adhered to.
High Risk	Very likely to result in a quality issue if not addressed and actioned.

Following the stated risk rating, a reasoning for the score is provided. Reasoning is subjective, based on the auditor’s experience, information provided and any supplementary information, such as the local regulatory landscape.

2.2 Manufacturing of brucite for Quality Assurance

The brucite in question has already been mined at Dandong City, Liaoning Province, China by Liaoning Danding Industrial Group Co. Ltd. Following a request to Planetary for evidence of quality control and quality assurance throughout the mining/manufacturing process (Q.65 – 122, Appendix A), none has been provided. Appendix A was submitted on 4 August 2023 with a response received on 31 August 2023. Unfortunately, no detailed answers to the statements and evidence requested were submitted.

Medium Risk – No evidence or overview of the manufacture/mining of brucite has been provided. Although testing has been completed on the material, there are still risks that other contaminants and poor manufacture/mining standards missed by the testing may be present.

As no evidence of manufacture quality control was received, a further question was raised around the batch shipped, milled and sampled being the only source for the duration of the trial (Q.55). In the response dated 31 August 2023, no specific statement answering this was identified. Depending on the answer to this question, a potential risk is present if Planetary are to procure more brucite from a varying batch. If this is to take place, it is recommended the following should be undertaken through an on-site audit.

The manufacture audit should align with ISO 9001:2015 and cover the following (where applicable):

- Specification of component materials
- Verification component materials received are to specification
- Handling and storage of all component materials and chemicals
- Processes and procedures for quality control
- Quality control checks and sampling (with focus on asbestos)
- Inspection, calibration and maintenance of equipment
- Management control and leadership
- Training and competence of workforce

WRc requested to see evidence (Q.56 and Q.58) of the batch number for the brucite so this could be traced back to the mine, with a ‘Bill of Lading’ provided (B/L NO. SOKFCNYK2107001) in Exhibit 4 of the 31 August 2023 data submission (Appendix F). However, this seemingly relates to the order and not the batch reference of the brucite that was ordered and delivered. There was also no evidence provided that gives assurance the batch of brucite used for this trial is the one that was sampled by the two laboratories.

Medium Risk – Not having a batch or reference number to this material makes traceability difficult and complex, especially with regards to the testing that’s been undertaken. If there are issues with this material further down the line, then understanding its journey back to source is essential. It also makes it hard if further batches are added to this trial or future ones to ensure quality control and manage any potential quality parameter failures.

Differing brucite manufacturing processes could introduce varying levels of contaminants into the material, which could subsequently impact on the risk that the MH poses on the environment (Section 5.2).

2.3 Storage, transport and quality assurance

2.3.1 Storage & Transport – China to Houston, Texas

Following mining in China at the Liaoning Danding Industry Group Co. Ltd, the material was bulk transferred to Cimbar Performance Materials at Houston, Texas (left photo of Figure 2.1) following only blasting, excavation, and screening.

Following storage at Cimbar Performance Materials in Houston, and an initial round of sampling and impurities testing, material deemed by Planetary to meet purity standards was milled. The material was milled down to D50 10 microns by Garrison Minerals LLC with the final UM10 product in 1-tonne super sacks ready for shipment (see right photo of Figure 2.1). Storage of the brucite at Cimbar Performance Materials is covered under ISO 9001:2015 (Appendix G), although no report was sent to understand the current status and any non-conformances identified during their last audit.

Figure 2.1 Brucite pile before milling down to D50 10 micron (left), final UM10 product in 1-tonne super sacks ready for shipment

The milling of the brucite was undertaken by Cimbar Performance Minerals at their Houston, Texas facility using a Raymond Roller mill as depicted in Figure 6 of Planetary's 31st August 2023 submission. As samples had already been taken before this point, quality control is crucial to ensure the milling process does not introduce any further contaminants into the material, as this could influence any risk MH may pose to the environment (Sections 5.1 and 5.2). There was no evidence provided of Garrison Minerals LLC's quality management system (e.g., ISO 9001:2015) to have assurance their processes ensure the quality control and low risk of contamination whilst processing materials.

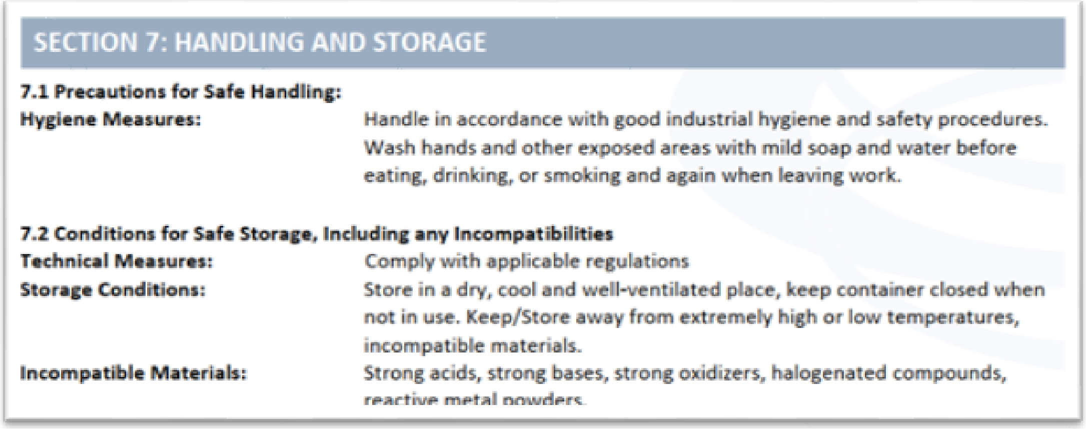
High Risk – As sampling has occurred prior to the milling, evidence of Garrison Minerals LLC quality control procedures should be sought due to risks of contamination to the product. A potential mitigation is to run the tests again at accredited laboratories for asbestos and material characterisation.

If evidence is requested for Garrison Minerals LLC quality control, the following areas are recommended:

- Handling and storage of all component materials (photos of storage piles and labelling).
- Processes and procedures for quality control through milling processes (ensuring no cross contamination to previous batched milling).
- Quality control checks undertaken (pre, during and post milling).
- Evidence of the procedures being undertaken (ideally for this brucite batch) which could be records, photos, etc.

Following milling by Garrison Minerals LLC, section 7.2 of their safety data sheet for brucite states that when not in use, the brucite container should be stored in a dry, cool and well-ventilated place with the container 'closed' (Figure 2.2). The current storage of the brucite is in 1-tonne sacks and it should be confirmed if the storage requirements are based on safety or quality needs.

Figure 2.2 Excerpt from Garrison Minerals LLC's Safety Data Sheet showing storage requirements.



SECTION 7: HANDLING AND STORAGE

7.1 Precautions for Safe Handling:

Hygiene Measures:	Handle in accordance with good industrial hygiene and safety procedures. Wash hands and other exposed areas with mild soap and water before eating, drinking, or smoking and again when leaving work.

7.2 Conditions for Safe Storage, Including any Incompatibilities

Technical Measures:	Comply with applicable regulations
Storage Conditions:	Store in a dry, cool and well-ventilated place, keep container closed when not in use. Keep/Store away from extremely high or low temperatures, incompatible materials.
Incompatible Materials:	Strong acids, strong bases, strong oxidizers, halogenated compounds, reactive metal powders.

2.3.2 Storage & Transport – Houston, Texas to Hayle WwTW, Cornwall

On completion of the milling stage at Garrison Minerals LLC, the material was then shipped in a shipping container to the UK through the London Gateway Port (Figure 2.3) and stored at FlueChem's storage facility in Southampton where it awaits sign off for the trial. The product is to be stored in Southampton where it will be watertight and free from potential of contamination.

Figure 2.3 Brucite arriving at London Gateway Port – May 2023

If the Environment Agency allow the trial, the material will be transported by road to Hayle WwTW where it will be prepared into a slurry and added to the final effluent. Any brucite transportation requirements will impact on the net CDR benefit that adding MH at Hayle WwTW would have. This is discussed further in Section 6.1.

No risks have been identified with this section.

2.3.3 Quality Assurance

As previously described, some of the brucite (UM10) has already been manufactured and has been transported from the manufacture site in China to Cimbar Performance Materials at Houston, Texas. WRc have been provided the Material Data Sheet from Garrison Minerals LLC (Appendix B) which covers the hazard identification, accidental releases, transport, Exposure/PPE, composition, fire, first aid, toxicological, ecological and disposal. The completion of this data sheet will need to be checked against Control of Substances Hazardous to Health 2002 (COSHH) to ensure full compliance is attained in the UK for handling and transporting this material.

Alongside the material data sheet are two sets of analysis and their respective accreditations:

1. Eurofins Reservoirs Environmental - Asbestos Test Result (Appendix C)

2. SGS Canada Inc. - Characterization of Magnesium Hydroxide Test Results (Appendix D)

A data request was sent by WRc asking for evidence (Q. 57 and Q. 59) of the two laboratories' accreditations (for example to ISO 17025) for the tests they completed. Evidence was submitted for Eurofins Reservoirs Environmental Inc. which demonstrated their ISO 17025 Accreditation for Asbestos Fibre Analysis.

Evidence was also provided to give assurance that the SGS Canada Inc. laboratory tests were undertaken in controlled manners using best practice under full quality control following independent reviews. Confidence in the quality of the brucite is key to understanding the impact its addition will have on the receiving waterbody. Any inaccuracies in the characterisation of brucite will have an impact on the existing environmental hazard and environmental toxicology assessments (Sections 5.1 and 5.2, respectively).

Once the material had arrived at CIMBAR, 500 tonnes was segregated and SGS Minerals Canada Inc completed a trace metals and particle size distribution analysis. No evidence has been received as to when the Eurofins test for asbestos content was undertaken and this should be understood. There is currently no way of auditing the trail from the batch of brucite through to these two samples.

Medium Risk – It is not clear from evidence that the samples are from the batch being proposed for use at Hayle WwTW and this should be confirmed as there is a risk a different batch was tested and therefore the quality of the brucite used for the trial is unknown. It is recommended the EA has full confidence that the tests completed on the brucite are accurate and complete, and undertaken before any further potential contaminants be introduced.

2.4 ESG considerations of the brucite manufacturing

Social responsibility auditing can be undertaken at any part of a supply chain, usually where activity involving social and environmental risk is material to the end company's impact and is a central component of ESG performance. The brucite sourced by Planetary may originate from a mine run by Dandong Riming Mining Co., however this cannot be confirmed due to potential pooling of material by the manufacturing entity; 'Liaoning Danding Industrial Group Co. Ltd.' As such, no affirmative statements can be made about the mine with regards to social responsibility.

Evidence requested in relation to social responsibility is detailed in Appendix E. While the general information regarding regulatory and mining-related compliance requirements provided by Planetary helps to form a generic picture, no information provided can enable substantiated conclusions to be reached with regards to the mine or the China-based manufacturing company (Liaoning Danding Industrial Group Co. Ltd.). As such, a more general review of social responsibility risk has been undertaken covering both the mine and the manufacturing company, to provide the Environment Agency with an understanding of the context within which the brucite was sourced.

2.4.1 General governance

The brucite is suspected of originating from Liaoning Province. The quoted mine is roughly located in the southeast corner of Liaoning Province, near the border with North Korea (Figure 2.4).

Figure 2.4 Location of Liaoning Province

Source: Google Maps

The region is known for its mining industry, as well as metal processing, machinery, and chemicals manufacturing. The Chinese mining sector has been exponentially growing in the last few years, following a push to decrease reliance on imports; China's 14th Five-Year Plan (2021–2025) significantly elevated the importance of mineral and energy security.

The mining sector is subject to multiple pieces of legislation and is mostly governed by the National Mine Safety Administration China (NMSA) on matters of social value. The Mineral Resources Law ("MRL") is the national law governing the prospection for and extraction from mines in China and the registration of mining rights. The Environmental Impact Assessment Law defines the compliance requirements for mine commissioning, operation and decommissioning with respect to environmental impact. Other laws relating to mineral resources activities can be found here: https://en.cgs.gov.cn/laws/ls

No public records were found in relation to the active regulation of the sector, therefore the level of scrutiny that companies are subject to is unknown. News articles were found citing a recent increase in the number of mining accidents recorded per year (Xu, 2023).

It is likely that Dandong Riming Mining Co. holds a business license and has had to undertake an environmental impact assessment, as well as other measures to demonstrate its ability to operate competently, due to the local compliance requirements of other purchasers in the supply chain and usual business practices in China (operating without a business license could result in criminal charges and is not a known common practice). The likelihood of bribery and corruption is not possible to ascertain given the information available.

Medium Risk – While basic levels of governance are likely to be in place due to the working norms in China, there is no evidence to confirm the level of due diligence and compliance at the mine.

2.4.2 Social (Health & Safety, Labour, Modern Slavery)

Worker rights in China have steadily improved over the last few decades, however the mining industry is high risk due to the level of manual labour, site-based work and machinery involved. In general, the social risks for workers and those in surrounding areas will be present in all mining communities, and without evidence of mitigating measures taken, the social risk present in this case cannot be determined.

Medium risk – No evidence is available to determine the general social risks for workers and those in surrounding areas.

Forced labour, child labour and modern slavery

In the report provided by Planetary, Cimbar Performance Materials Inc states they do not use raw materials produced with child or forced labour, and has worked and will continue to work to identify and address child labour, forced labour and/or human trafficking issues stemming from the country's operations.[1] Unfortunately, these statements cannot be substantiated. Cimbar Performance Materials also provided their ISO9001:2005 certificates, however without the supporting audit report their certification cannot be authenticated. China's working age is 16 and is generally considered to be adhered to.

There is no indication of the number of workers at Dandong Riming Mining Co., whether they live in dormitories on site or in local towns, or whether they are Chinese nationals or migrant workers.

Medium risk – No evidence is available to determine the likelihood of forced labour, child labour or modern slavery. While the risk of child labour is low compared to other nearby nations, there is nothing to contextualise the risk of forced labour or modern slavery.

Working hours

Working long hours is a cultural norm in China, and overtime is widely encouraged. Taking one day off after thirteen days of working is encouraged as best practice in China, to avoid worker fatigue.

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[1] Pages 32, 33, 34 of the Planetary report

Medium risk – Long working hours in a high-risk sector can increase the likelihood of accidents and burnouts. However, there is no evidence surrounding the specific working hours at the mine company.

Remuneration

While online sources are not known to be highly reliable on regional salary data in China, they have suggested salaries average between 29,200CNY (£3,198) to 69,622CNY (£7,624) per annum in Liaoning Province (Salary Explorer, 2023; CEIC, 2023). One source provided Liaoning's minimum wage as 17,040 CNY (£1,856), which is among the lowest in China (China Briefing, 2023). It is well known that salaries have been increasing in China by roughly 10% per year which has resulted in varied levels of increased quality of life.

Medium risk – Low wages can often indicate workers' quality of life and worker rights are more at risk than those on proportionally higher wages within the nation. However, general quality of life in China is understood to be improving.

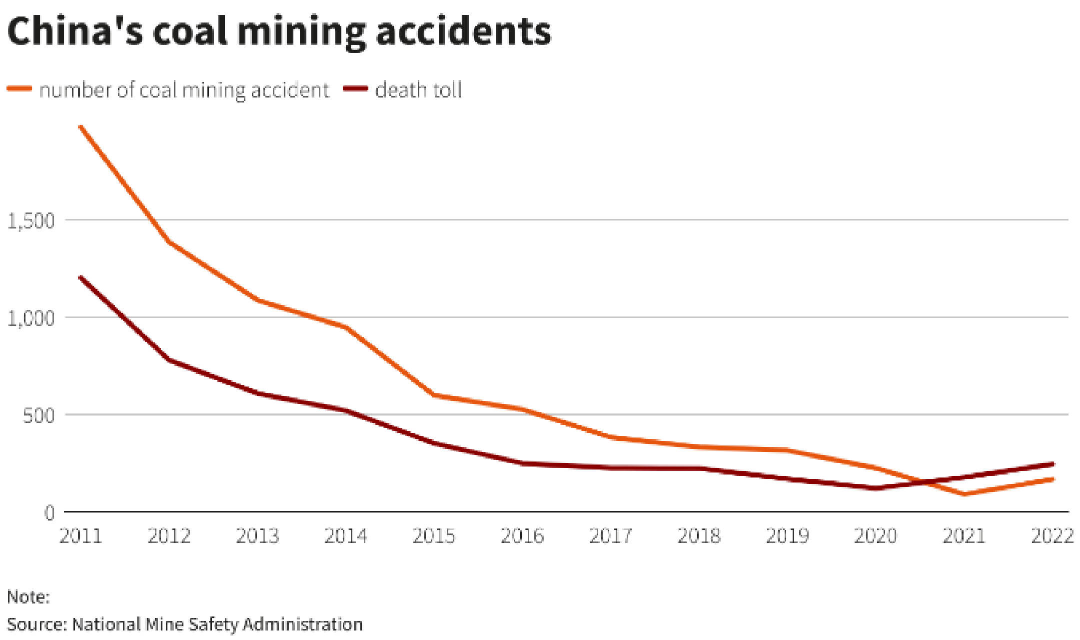
Health and Safety

Health in mining is mainly regulated under the Mine Safety Law and the Regulations for the Implementation of the Mine Safety Law. Safety in mining is mainly regulated under the Law on the Prevention and Control of Occupational Diseases.

Accidents

While Chinese mining operations are subject to a range of legislation, and additional levels of criminal offences introduced in 2021, the number of accidents rose from 91 in 2021 to 168 in 2022, in conjunction with China's recent push to increase focus on growing the sector (Xu, 2023).

Figure 2.5 Coal mining accidents in China, 2011-2022



The National Mine Safety Administration is concerned with the lack of focus on safety, which if a widespread issue, may reflect on the mining-related activity within Liaoning Province (Xu, 2023). This may be a brief response to the new policy approach, and therefore may settle over time, however given this trend across the mining sector, there is an increased likelihood that Planetary's supply chain may include low or insufficient levels of health and safety compliance.

High risk – The rise in mining-related accidents raises questions surrounding the efficacy of cited legislation and enforcement activity.

2.4.3 Asbestos

Asbestos mining is still an active industry in China, and brucite is regularly sourced from mines that also contain asbestos fibres. Whether asbestos mines are operational or decommissioned, the health and safety risks surrounding them are sizeable. Many countries have chosen to ban asbestos production due to the risks it poses during extraction and use. The main health risks include mesothelioma (cancer) and other asbestos-related diseases. Workers and company management must take great care to avoid exposure to asbestos; this is usually a requirement of holding a mining license, so some level of protocol is expected to have been shown to authorities.

High Risk – Asbestos can have life threatening impacts on workers. Purchasers of mining products from regions where asbestos mining is still an active industry should undertake audits of the specific mines in question to assess the likelihood of overlap.

2.4.4 Environment

There are a range of common environmental impacts that mining-related activity can cause, including:

- Habitat destruction
- Water pollution
- Soil pollution and erosion
- Air pollution
- Acid Mine Drainage (AMD)
- Tailings Dam Failures (mining waste exposed and spread)
- Noise and vibration

Articles have been found relating to soil heavy metal pollution and a history of soil magnesium contamination in Liaoning Province, likely due to discharges from mines within the area (Wang, et al., 2015). Environmental pollution is a known issue in China, however in recent years, efforts have been made by the government to inspect high impact sectors. While there is no evidence regarding the level of inspection of the mine in question, in accordance with the Environmental Impact Assessment Law, an EIA will likely have been conducted for the mine, detailing how the company intends to prevent damage, although this has not been made available for this audit.

Medium Risk – There is no evidence to support the level of compliance for the mine company's environmental impact, and there is known damage caused by mines in the region. The EIA requirement is positive but cannot indicate ongoing compliance.

3. Wastewater treatment works permit and process

3.1 Prior work

WRc has previously looked at the use of natural alkaline minerals, as a waste stream, applied direct to the aeration units within an activated sludge plant as a means to capture carbon (Hodkin *et al.*, 2021). Wollastonite was used as the example mineral, because of the availability of dissolution rates (DR) data, with the material being waste particle sizes of 2.5 to 0.01 mm. Only the 0.01 mm particles had a useful DR, of 47% after one year. The project concluded that even at 0.01 mm the limits on dosing to avoid high suspended solids (SS) in the aeration tank restricted the utility of the approach.

3.2 Impact on the treatment plant

The MH is dosed after the ultraviolet (UV) plant, so is not expected to interfere with the wastewater treatment plant. The MH will increase the immediate local concentration of suspended solids, and may result in the discharge prior to dilution / dissolution being the colour of MH – white – rather than the faint off-yellow to clear associated with treated final effluent.

As inferred from the existing permit, Hayle WwTW treated effluent and storm sewage share the same outfall, and as such MH will be further diluted in the outfall pipe during storm conditions, above the flow to full treatment that is presently considered in the Planetary report. The current permit for Hayle WwTW also includes permits for aluminium and iron of 10,000 µg/l, metals which have also been detected in the supplied MH (see also Section 5.2.1).

3.3 Suspended solids impact on the mixing zone

The MH is to be dosed with a gradual increase in the quantities over the trial period. The stated quantities, and expected concentrations allowing for dilution, are summarised in Table 3.1. Planetary have used a 250 m radius from the outfall as the initial mixing zone. The WRc-calculated concentration is lower than that reported by Planetary, and both are lower than the EA requirement that the suspended solids (SS) should not exceed 100 mg/l outside the mixing zone (Planetary Technologies, 2022). No allowance has been provided for the concentration of SS in the final effluent or in the background sea, but the calculated rise in concentration is small compared to the EA allowable value of 100 mg/l, and the allowable instantaneous value in the final effluent of 150 mg/l as a 95-percentile (approximately, 75 mg/l as an average), is not expected to be of concern, though the current performance of Hayle WwTW with regards to its SS consent has not been assessed.

The flow used is that reported by Planetary as the ‘average flow’. This is the lower 35-percentile value of the flows recorded over the period January 2020 – December 2022. Flow data for 2023 was provided only as a graphical image, and records that for the (unspecified) period plotted, 2023 had higher flows than for 2021 or 2022. The percentile plot provided by Planetary is reproduced as (Figure 3.1). The flow data was recorded at 15-minute timesteps, a resolution that is appropriate for capturing diurnal variations in flow. The final effluent flows are normally greater than the values used for the concentration / dilution assessments, and the dilution used is the lowest recorded in the Planetary Update 2 report (Planetary and South West Water, 2023a). The true impact of the dosing on the solids concentration is expected to be much lower than these estimates.

The mixing studies presented in the Planetary Update 2 report state that the CORMIX estimates of mixing are likely to underestimate the degree of mixing, as they do not account for wind effects nor that the overall flow velocity increases with distance from the outfall. Thus, the modelling predictions are conservative for the expected concentration within the mixing zone. Near-field mixing is discussed further in Section 4.2.

Table 3.1 Magnesium hydroxide concentrations for various dosing scenarios

Magnesium hydroxide dose	Final effluent flow, l/s	Outlet concentration, mg/l	Concentration after diffuser dilution, mg/l [1]	Planetary reported concentration after dilution, mg/l
8 kg/min [2]	285 [3]	468	0.94	2.2
4 kg/min, 8 h/d [4]	285	234	0.47[5]	NA
12 kg/min [6]	285	702	1.40	NA

[1] Dilution factor of 500, Planetary update 2 report, p. 6

[2] Update 2 report, p. 6

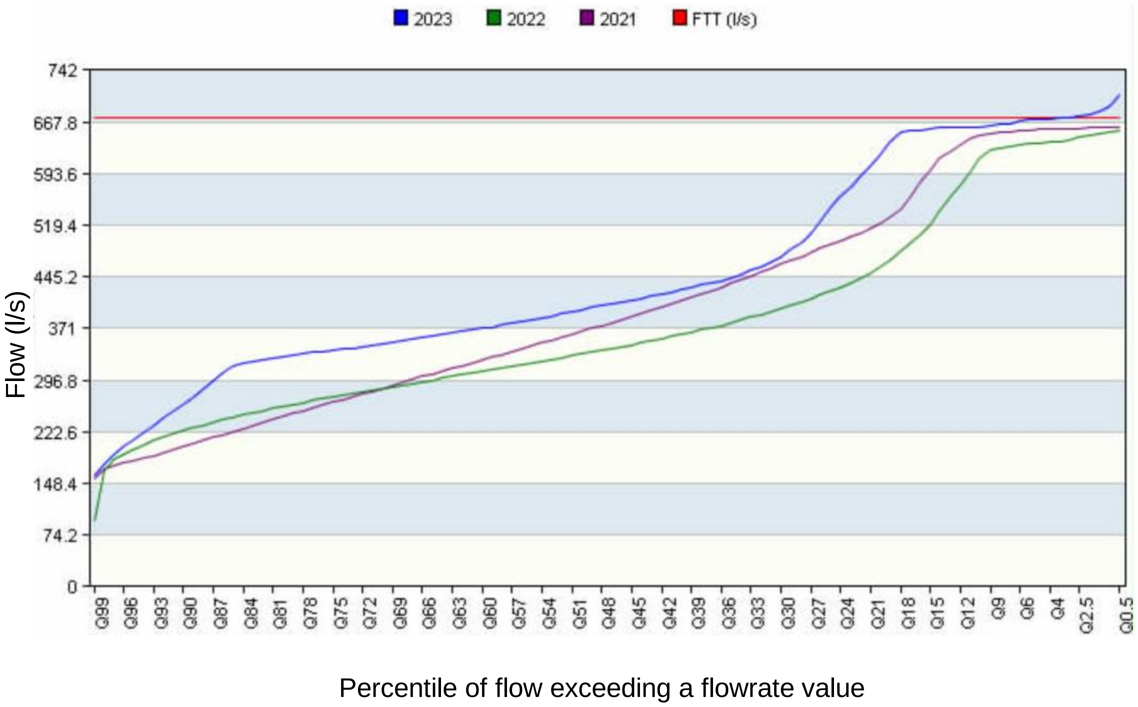
[3] Average flow, p. 130 of Update 2

[4] Update 3 report p. 6 (Planetary and South West Water, 2023b)

[5] No allowance for dosing for 8 h a day

[6] Update report 3, p. 7

Figure 3.1 Planetary-provided percentile final effluent flows. FTT is the flow rate quoted in the storm overflow permit for Hayle WwTW (flow to full treatment).



3.4 Dissolution rates

Before MH may react with CO_2 it needs to be dissolved. Therefore the dissolution rate plays an important part in the overall reaction rate. The dissolution rate is usually quoted as a rate per surface area of particles – for the same mass of solids small particles have a greater surface area, and therefore dissolved faster. The reaction can be approximated by the following equations, where the first step is the conversion of solid magnesium hydroxide to the dissolved form.

$$Mg(OH)_{2(s)} \rightarrow Mg^{2+} + 2OH^-$$
$$Mg^{2+} + OH^- + CO_{2(aq)} \rightarrow MgHCO_3{}^-$$
$$MgHCO_3{}^- + OH^- + CO_{2(aq)} \rightarrow Mg(HCO_3)_2$$

Dissolution also releases any other metals in the solids into the water, and therefore needs to be assessed for the impact on toxicity (see Section 5). In addition dissolution means that the suspended solids concentration is removed, by the mass of solids dissolved, enhancing compliance with the EA suspended solids limits.

The DR for MH used in the Planetary-commissioned modelling appear to be curve fits taken from a graph in Pokrovsky and Schott (2004), with the focus being the effect of pH on the DR. A comparison of the two is given in (Figure 3.2) and shows that the correlation is a good match with the raw data. Pokrovsky and Schott performed experiments with magnesium concentrations ranging from 10^$^{-6}$ (i.e., µmol/l) to 5*10^{-4} mol/l (i.e., 500 µmol/l). These all allow brucite to dissolve easily. Seawater has a magnesium concentration of 50 mmol/kg which is 100 times higher than those of Pokrovsky and Schott. Dissolution rates from the Pokrovsky paper will therefore likely be over-estimates given the lower magnesium concentrations.

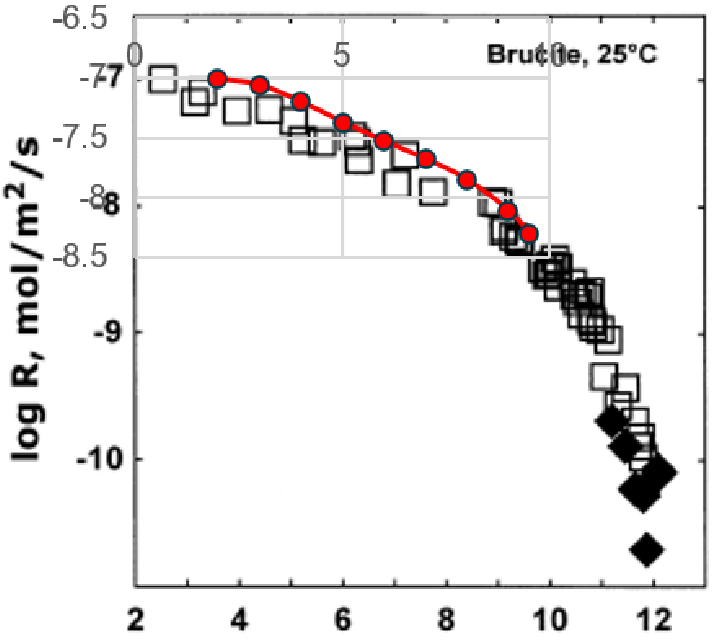
Pokrovsky and Schott state that the values used are steady-state values, and that the initial dissolution rate could be increased by up to 30% when the stirring speed was increased from 200 rpm to 1,000 rpm. Power consumption is proportional to the cube of the impeller speed, while the mixing intensity is proportional to the square root of the power – thus, the mixing intensity is proportional to the impeller speed raised to the power 1.5. A five-fold increase in the impeller speed therefore increases the power consumption by around 125, and the mixing intensity by over 10-fold. The results do not record the mixing speed being used, and the paper does not discuss what effect the mixing speed has on the steady-state DR. There is a possibility that the DR are higher than may occur for the ocean dissolution trials, because of the difference in mixing intensity between an impeller-agitated test solution (with potentially high-power input) and a hydraulic jet with mixing by ocean currents.

Bharadwaj *et al.* (2013) also looked at the effect of impeller speed. For their test system they found that impeller speeds below 500 rpm resulted in unstable pH control; the mass transfer rate increased approximately linearly with impeller speed from across the range 300 to 700 rpm, and above that plateaued, with the test temperature set at 52°C. With the high temperature and the different experimental conditions compared to the ocean dosing, the numerical values should not be relied upon, but the implication is that low mixing rates will result in a reduction in DR, corroborating the findings of Pokrovsky and Scott.

The original data was presented at 25°C and the modelling work has used the same DR in winter as in summer. This is likely to overstate the dissolution, and therefore the carbon dioxide (CO_2) drawdown from MH addition (considered further in Section 6.1). However, there is also a strong dependence on the DR with pH, and the Planetary model includes temperature dependencies on other aspects of the pH calculations. A reduction in the DR results in lower pH values, and lower pH values promote a higher DR. The overall effect of pH and temperature may result in a minor change in temperature. Repeating the Planetary model with the inclusion of a temperature dependency on the DR would be needed to quantify the combined effect.

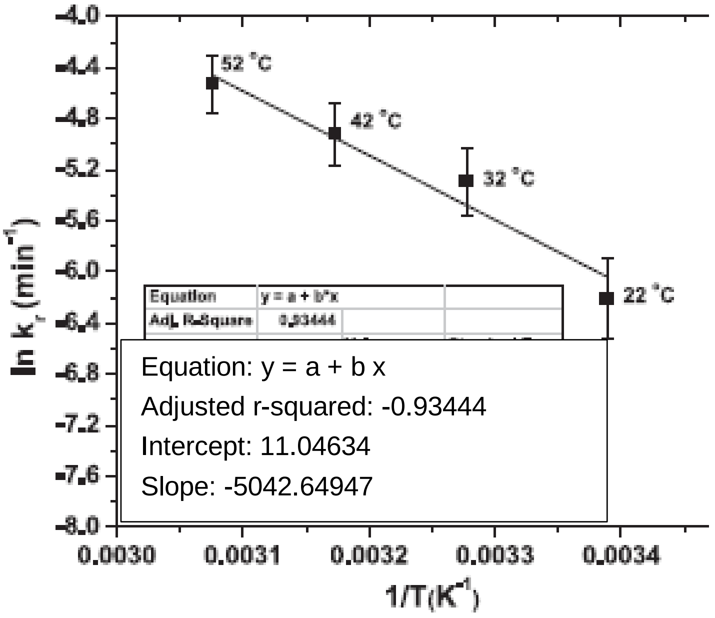
Bharadwaj *et al.* (2013) present data (Figure 3.3) which shows that there is a strong relationship with temperature. Based on their data, the rate at 17°C is 63% that at 25°C, and at 10°C the rate is reduced to 41% of that at 25°C. On this basis the DR used in the modelling for the winter conditions (temperature at 10°C) should have been closer to half the value used. This will also impact on the maximum carbon sequestration potential (Section 6.1). The laboratory trials presented by Planetary in the Update 2 report (p. 12) state that for the trials the DR after 10 days became limited by the rate of CO_2 transfer into the water. It is not clear if the modelling work included that the DR would decrease as the saturation level of MH increased (i.e., that CO_2 dissolution was controlling the conversion of the hydroxide to bicarbonate, and thereby influencing the DR of MH) or assumed that dissolution would proceed at the rate given by the correlation.

Figure 3.2 Comparison between Planetary correlation and raw data for magnesium hydroxide dissolution rate



Red line: Planetary model

Figure 3.3 Variation of magnesium hydroxide dissolution rate with temperature



Equation: y = a + b x

Adjusted r-squared: -0.93444

Intercept: 11.04634

Slope: -5042.64947

The model prediction is that the CO_2 drawdown is much greater in winter than in summer (Table 3.2), and this means that the model results may overstate the benefits. Normally dissolution is enhanced by higher temperatures, but WRc recognises that with magnesium hydroxide there is a strong pH effect that may be more important than that of temperature.

Table 3.2 Carbon dioxide drawdown by magnesium hydroxide addition

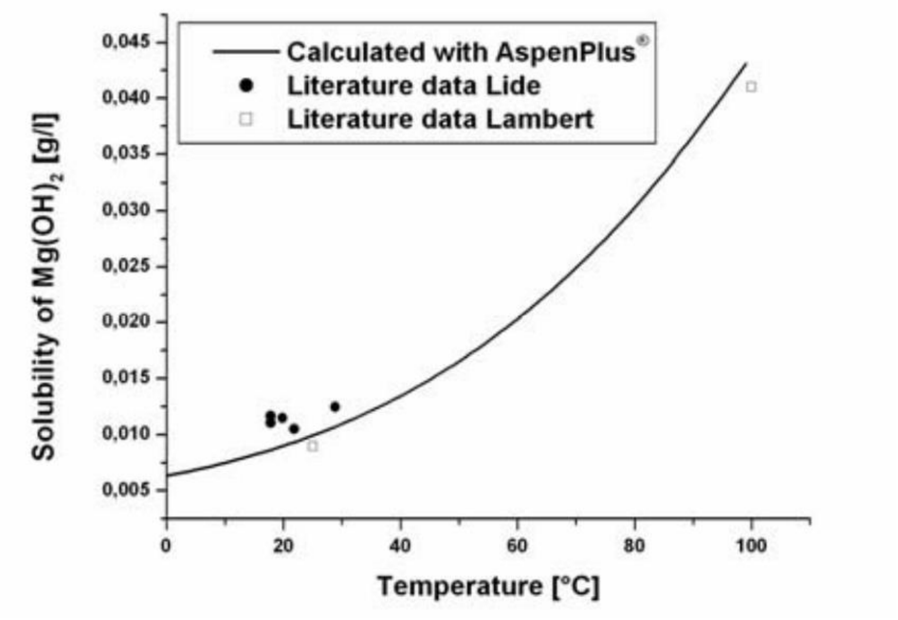
Dosing rate	Winter (10°C)	Summer (17°C)
158 kg/d $Mg(OH)_2$ (dissolved)	21 tonnes	10 tonnes
158 kg/d dissolved + 112 kg/d particulate $Mg(OH)_2$	33 tonnes	15 tonnes
158 kg/d dissolved + 842 kg/d particulate $Mg(OH)_2$	110 tonnes	48 tonnes

Data from Table 14, p. 188, of the Planetary Update 2 report. The values quoted are the increase over the un-dosed CO_2 drawdown, which the modelling estimated as 20,555 tonnes in winter and 52,577 tonnes in summer.

The initial dissolved concentration of MH is the same across summer and winter. At an average final effluent flow of 285 l/s, this is equivalent to 6.4 mg/l. The solubility of MH under winter conditions (Schöggl *et al*, 2006) is close to this value; the summer solubility is higher (Figure 3.4).

Dávila *et al.* (2016) have a more complex set of reactions for MH and CO_2, including the formation of magnesium calcium compounds. At ambient pressures and temperatures, the magnesium calcium compounds are predicted to be a minor component, so the Planetary assumptions are acceptable. With increasing depth there is a shift to the occurrence of more of the magnesium calcium compounds, resulting in enhanced capture of CO_2 compared to the Planetary assumptions.

Figure 3.4 Solubility of magnesium hydroxide



3.5 pH

It is estimated in the Planetary Update 2 report that the pH value will be in the range of 8.04 – 8.1 as an average across the whole modelled zone, decreasing slowly with time. The pH at the dosing point is 9.2 (MH 468 mg/l), reducing to 6.7 with the concentration estimate at the end of the mixing zone being 0.94 mg/l. pH was calculated using the Aquion interface to PHREEQC (Aquion, 2023). Using the higher MH concentration reported by Planetary, of 2.2 mg/l, the pH increases to 7.1. The pH values are calculated for MH with alkalinity specified as 2.4 mmol as H_2CO_3. These values are lower than calculated by Planetary; however, the Planetary values reflect experimental trials with CO_2 and MH (Li *et al.*, 2014; Cheng *et al.*, 2013) where the low pH from the equilibrium calculations as reported by PHREEQC occur after an initial increase in pH through the MH dissolution. The dosing of MH may confer some benefit with regards to ocean acidification (Section 6.2).

No pH limit was found in the site permit provided, but Planetary has recorded that there is a pH limit of 8.5 for the outfall (as stated in the EA request for a proposal for this project - SWW EA Proposal 2.0, p. 11). With Planetary working to a 'stop dosing' pH trigger of 9.5 these calculations indicate that there should be no problems related to the existing pH permit. Experience in using MH to control odours at wastewater treatment plants (Ganigué *et al.*, 2016) would suggest that the pH does not exceed approximately 9.

The parameter values provided in the Planetary Update 2 report (p. 154) are calculated from equations in the paper by Dickson *et al.* (2010) and are extended over standard references to include a salinity factor in the equilibrium constants. Checks against clean water values produce values that are comparable, and WRc would regard the salinity factor as making the Dickson *et al.* approach more valid.

3.6 Pipe blockage risk

Various precipitates may be formed, of which the greatest concern raised by Planetary is the formation of struvite. Within WwTW struvite is at greatest risk of formation after sludge digestion, where the temperatures are raised, and ammonia concentrations increased. There are no ammonia or nitrogen permit values for Hayle WwTW, so WRc assumes that there is no ammonia removal. Struvite formation is more likely with high pH and lower temperatures, so the addition of MH does increase the risk. However, the ammonia concentrations in wastewater are less than found in digester supernatants. With typical wastewater concentrations of 40 mg/l ammonia and 10 mg/l phosphorus, we estimate that the ionic product is several orders of magnitude below the typically quoted K_{sp} values, such as in Harada *et al.* (2006). Whilst the risk is low, any pipe blockage could impact on dispersion and plume modelling (Section 4.2).

3.7 Summary

The following conclusions are reached from the analysis of the dosing of MH into the final effluent:

- As expected, there is no effect on the operation of the WwTW as the addition of MH takes place in the final effluent system and therefore does not affect the performance of the treatment plant.
- WRc concurs with Planetary that struvite precipitation is not anticipated.
- WRc predicts slightly lower concentrations for magnesium hydroxide in the mixing zone than the Planetary report, and that the concentrations are low compared to the trigger concentrations of SS exceeding 100 – 150 mg/l.
- WRc predicts lower pH values than Planetary report, but recognises that WRc’s tool is based on equilibrium conditions, and that the literature supports the short-term pH rises predicted by Planetary.
- The literature indicates that the complex ions present in seawater may enhance the ability to capture CO_2 compared to the model used by Planetary.
- The impact of the dosing near to the discharge point in the bay is not expected to increase the Suspended Solids (SS) by more than a few milligrams per litre. This is a small increase compared to the SS concentration permitted in the final effluent.

- The dissolution model used in the Planetary reports does not include a temperature effect, and therefore probably overstates the expected carbon capture in winter, and possibly also in summer. The interaction with pH means that estimating the degree of reduction would require re-running the model.

- Mixing intensity may also result in the model over-predicting DR, but it is not clear from reviewing the underlying paper if this is the case, or only affects the initial stage of dissolution – in which case the DR used may be low, ignoring the initial higher dissolution rates before the steady-state DR are reached.

- The uncertainty over the temperature and mixing effects, both of which may have over-estimated the dissolution rate, mean that WRc would regard it as pragmatic to take samples from the bed near the discharge point, and radially out to the estimated end of the near/mid-field (around 200 – 250 m), to test for the potential of magnesium hydroxide accumulating in the sediment. Turbidity measurements both near the bed and in the water column will also allow for an estimation of the effect of MH particles accumulating in the near-field around the discharge point. WRc understand that such measurements are planned by Planetary.

4. Magnesium hydroxide dispersion modelling audit

Dispersion modelling was undertaken for the long sea outfall at Hayle WwTW to understand the dispersion offered by the existing outfall arrangement; and how the effluent concentration and the extent of the effluent plume, with the addition of MH, might vary from the immediate vicinity of the outfall (near-field) into the surrounding area until fully dispersed (mid-field to far-field). In addition, the water quality and dispersion model were used to predict the likely potential for CO_2 uptake. This section of the review constitutes a high-level review of the models used, whether they are appropriate and have been used in an appropriate manner to produce credible results.

The dispersion modelling tools selected for this investigation were Delft3D and CORMIX for the mid-field to far-field and near to mid-field respectively. They are industry standard models and are widely used specifically for the purpose of assessing the impact of effluent dispersion from a long sea outfall.

4.1 Hydrodynamic model (D-Flow) development

The hydrodynamic model was built using the adjustable mesh size module (D-Flow) within the Delft3D modelling suite. Its extent (domain), approximately 30km eastwards, westwards and offshore, and resolution, (grid squares 60 m x 60 m at the outfall to 120 m x 180 m at the boundaries), are appropriate for this type of study. The model has been used in 2D rather than 3D due to the limited variation in the vertical mixing in the water column i.e., the water column could be considered fully mixed, demonstrated through temperature measurements taken throughout the water column which were shown to be similar. This seems a reasonable and pragmatic simplification and has the benefit of saving computation time given the limited benefit to model negligible vertical stratification. Bathymetry data is taken from two sources: Coastal Science Ltd’s own dataset and the European Marine Observation and Data Network (EMODnet) Digital Terrain Model. It is difficult to comment on the former, but the latter is a European Commission-owned service with good governance.

The model boundary conditions are provided by a larger regional model, maintained by Coastal Science Ltd. This is usual practice although the extent of the regional model is not given.

The effect of wind has not been included within the hydrodynamic modelling, the effects can be relatively small, and as such this is not unusual. The wind effect has been included in the water quality simulations.

4.1.1 Model performance

Tidal levels

The model results show good agreement between modelled and predicted tidal levels at St Ives both against the performance criteria and visual inspection. It is noted that there are no other specific water level calibration data, and the hydrodynamic model was built for a previous study, although the date is not given. Modelled tidal range data is presented across the model extent but only validated for St Ives.

Tidal flows

The report states that when the hydrodynamic model was originally calibrated (no date given) only tidal diamond data[2] were available. The modelling report clearly states the limitations of using tidal diamond data, as it provides only representative localised tidal information independent of prevailing conditions. However, tidal diamond data is, or was, commonly used for calibration within the water industry. Additional data in the form of Acoustic Doppler Current Profiler (ADCP) survey data were used to compare with model performance and provide additional assurance of model integrity and that the model can predict flow of the right magnitude and direction. Comparison against both tidal diamond data and the ADCP data suggest that the modelled tidal flows are over predicted for the ebb tide. The tidal direction is matched reasonably well. Overall, the model results are acceptable and can be used with reasonable confidence given the normal limitations of coastal hydrodynamic modelling.

It is noted the ebb flows are predicted to be approximately 20% higher than those measured, as shown in the comparison with the ADCP data and the report states that this overprediction should be considered when interpreting the model output from the water quality modelling.

The drogues track results are difficult to comment on without knowing the duration of the release, but the assumption is for a single instantaneous release at high water and low water. The results show the direction and extent of the tracks to the northeast and southwest as expected, with a greater extent to the southwest, which is probably related to the over prediction of the ebb flows.

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[2] A tidal diamond is a way of describing the average tidal current conditions for a location by referencing them to the time of high water (either at the same location or at a remote location or port). Each diamond gives the average current speed and direction over a complete tidal cycle from six hours before the time of high water to six hours after. Usually, two sets of values are given – one for spring tides and another for neap tides. (UK National Oceanography Centre)

4.2 Near-field mixing CORMIX modelling

Modelling was undertaken with CORMIX primarily to help inform how the outfall should be modelled when using the water quality module within the Delft model (D-WAQ). CORMIX is used routinely for near-field assessments of outfall dispersion. Near-field in this circumstance is taken to be the area immediately around the outfall.

The outfall from SWW's Hayle WwTW discharges approximately 2km offshore. During wet weather conditions the outfall can discharge both treated flow and any additional stormwater.

The CORMIX modelling results have shown that when the outfall discharges at Dry Weather Flow (DWF), the plume rises to the surface approximately 50 m from the outfall. At this location, the report suggests that the water column can be fully mixed, particularly under higher flow conditions such as an ebb spring tide. Spring, neap, and intermediate tidal cycles were tested, and the results show that the plume rises to the surface at roughly the same location, but the spread and column mixing vary depending on the tidal conditions. Higher flows give rise to greater column mixing but a narrower plume, whilst slower flows conditions (neap tides and slack water) would allow the plume to remain in the upper part of the water column but with a greater spread. Results for a mean plume width of 47 m are presented, as is a mean column mixing of 82%, although it is not entirely clear how these figures were calculated, but they are not unreasonable. However, as CORMIX does not account for the additional mixing resulting from wave action, any optimistic assumption of mixing will be slightly ameliorated.

The location where the plume rises to the surface (approximately 50 m) has been termed the mid-field mixing area in this report and the results from the mid-field have been used for this exercise. The rationale for this is that results in the immediate mixing area (0 – 50 m) (near-field) are highly variable and unstable as the plume rises to the surface and that the mid-field results are more representative of the plume as it will be represented in the hydrodynamic model. Use of the mid-field results is reasonable, but with the caveats above relating to the assumptions of mixing and spread in the mid-field.

The results taken from the CORMIX mid-field assessment were used to define how the outfall was to be represented in the Delft water quality module, i.e., should the plume be applied throughout the whole water column or to the bed only (i.e., should the Delft WQ module be used in 2D or 3D), and whether the resolution of the grid was sufficient. Given the mean plume width of 47 m and the assumption that in the mid-field the discharge would be fully mixed, the discharge could be applied to one cell as the plume width was less than the grid spacing of 60 m x 60 m around the outfall, and that the discharge was assumed to be fully mixed within that water column. Given the model results and the assumptions regarding the nature of the plume above, the methodology for the representation of the outfall in the water quality module is reasonable.

However, under wet weather conditions the flows discharged from the outfall will be higher. Under these circumstances MH may be further diluted when discharged into the sea. The addition of stormwater may also impact on the plume and near field CORMIX modelling,

The extent and location of the plume will have an impact on the efficiency with which MH sequesters carbon (Section 6.3). There is a low risk of pipe blockage due to MH dosing and any potential subsequent struvite formation (Section 3.6). The model does not assess the impact that this would have on the plume, as is usual practice for dispersion modelling.

The report lists the modelled dilution factors within the mid-field area. These have been calculated using an average final effluent discharge flow of 300l/s. These factors range from a minimum dilution factor of 500 to a maximum dilution factor of 2,773. These modelled dilution factors will also have an impact on the environmental hazard assessment (Section 5.1).

4.3 Summary

The models used for this investigation, Delft2D, and CORMIX, are appropriate and have been built following recognised and accepted methodologies and data. The hydrodynamic model has not been calibrated against any field data, although ADCP data have been used to compare and verify against the results. The model performs reasonably well against the ADCP data but tends to overpredict ebb flows.

CORMIX was used to determine how the discharge should be modelled in the hydrodynamic model. CORMIX is a relatively simple mixing model and its output is used to confirm the plume extent and mixing within a water column in the near and mid-field areas of the outfall. The CORMIX results confirmed that the discharge, with its tendency to rise to the surface and become almost fully mixed at the mid-field (~50 m from the outfall), could be represented adequately by assuming it would be fully mixed within one cell in the hydrodynamic model with its current grid resolution.

It is noted that the hydrodynamic model tends to overpredict the ebb flows, as shown when compared to those from the ADCP data, and this would over predict the effects of dispersion and mixing. This may have implications for the water quality and dispersion modelling, although the modelling report suggests that this is not likely to be the case.

5. Environmental toxicology assessment

5.1 Environmental hazard assessment

5.1.1 Ecotoxicological Assessment of Magnesium Hydroxide

Acute toxicity to aquatic organisms

The available acute toxicity data suggest that magnesium hydroxide (MH) is of low acute toxicity to crustaceans and fish; and of low to moderate acute toxicity to algae. The 72-h EC_{50} for growth rate or yield inhibition in green algae *(Pseudokirchneriella subcapitata)* was >100 mg/l while 72-h EC_{50s} of 82-111 mg/l have been reported in the marine microalgae (*Skeletonema costatum*) (ECHA, 2023; Delacroix *et al*., 2023). In addition, 48-h EC_{50s} (immobilisation) of 170.6 mg/l (ECHA, 2023) and >439 mg/l (US EPA, 2023) have been reported for the water flea *(Daphnia magna).* The 96-h LC50s reported in the fish, fathead minnow *(Pimephales promelas)* and rainbow trout (*Oncorhynchus mykiss*) were 306.79 mg/l and 775.8 mg/l, respectively (ECHA, 2023).

Chronic toxicity to aquatic organisms

Chronic toxicity data for MH on aquatic organisms are extremely limited. No chronic data are available for crustaceans and fish and MH is of low chronic toxicity to algae based on 72-hr no observed effect concentrations (NOECs) of 100 mg/l and 25 mg/l in *Pseudokirchneriella subcapitata* and *Skeletonema costatum,* respectively (ECHA, 2023). However, according to ECHA (2023), the long-term toxicity of MH to fish or daphnia is unlikely to occur based on its physico-chemical properties (slightly soluble in water (8 mg/l in seawater) and low sediment sorption potential), its breakdown pathway (degradation to magnesium and water in the environment over time), and the widespread presence of magnesium ions in the natural environment as an essential nutrient in plants and animals.

5.1.2 Persistence, Bioaccumulation and Toxicity (PBT) Assessment

MH does not meet the criteria to be classified as dangerous under the Classification, Labelling and Packaging (CLP) Regulation (European Commission) No 1272/2008 nor does it meet the criteria to be classified as persistent, bioaccumulative or toxic (PBT) under the Registration, evaluation, authorisation, and restriction of chemicals (REACH) Regulation (ECHA, 2023).

5.2 Environmental risk assessment

5.2.1 Trace metals compliance with Environmental Quality Standards

Some metals including those listed as priority substances or specific pollutants under the water framework directive (WFD) were detected in the brucite or MH analysed by SGS Canada on behalf of Planetary (Table 1-1 of Update 2 report).

Planetary reported that the concentrations of the metals in the effluent and receiving water were below their respective environmental quality standards (EQS) recommended under the WFD (Standards and Classification) Directions for acute/maximum allowable concentration (MAC) and chronic/annual average (AA) limits (Tables 1-2, and 1-3 of Update 2 report).

An exceedance of the EQS for the marine water may result in adverse effects on the aquatic organisms.

To assess the compliance of the metals with their respective acute and/or chronic EQS limits for the marine water, the following data provided by Planetary and South West Water (SWW) (pages 6 - 7 and 130 of Phase 2 Update 2 report) were used.

- 8 kg/min MH addition rate
- Effluent flow rates of 300 l/s (nominal), 285 l/s (average daily), 120 l/s (night)
- Worst case 500-fold dilution factor

Planetary developed an Environmental Quality Standards screening tool to compare metals concentration at various dosing rates assuming average effluent flow rates and 100% dissolution of metals (which is highly unlikely in the natural environment and therefore overly conservative). An example output of this screening tool was provided in Tables 1-2 and 1-3 of the Update 2 report using an 8kg/min (16L/s) 54% density MH slurry.

Using the average concentrations of the trace metals (g/t) detected in MH provided in Table 1-1 of the Planetary Update 2 report, the effluent/pipe concentrations of the individual metals were calculated by WRc in this report using 8 kg/min MH addition rate and effluent flow rate of 300 l/s as shown in Table 5.1.

Using the originally proposed 8 kg/min MH addition rate, an effluent discharge rate of 300 l/s, the pipe concentrations calculated by WRc and assuming 100% of the metals were to dissolve in the effluent (which is highly unlikely in the natural environment), the EQS limits were not met in the effluent/pipe for Pb, Hg, Fe, Ag, Cr and Zn. However, upon 500-fold dilution of the effluent by the receiving water body the concentrations of all the metals complied with their respective EQSs (Table 5.1).

With a worst-case night flow rate of 120 l/s and 8 kg/min MH addition rate, EQS limits were exceeded for Pb, Hg, Fe, Ag, Cr, Co, Ni, Sn and Zn in the effluent. Allowing a 500-fold dilution of the effluent by the receiving marine water, the EQSs were met for all the metals (Table 5.2). The current wastewater treatment works (WwTW) performance, which specifies 10,000 µg/l for Al and Fe (Section 3.2), has not been assessed, but the 500-fold dilution of the receiving watercourse means that this is not thought to pose a significant risk to the respective EQSs.

In the Planetary and SWW Phase 2 Update 3 report (pages 7 - 8), a revised maximum MH addition rate of 12 kg/min or 720 kg/hr was proposed.

For a revised MH addition rate of 12 kg/min, and an average daily flow rate of 285 l/s or the worst-case flow rate of 120 l/s, the EQSs were not met in the effluent for some of the metals as shown in Tables 3 and 4. However, by allowing a 500-fold dilution of the effluent by the receiving water all concentrations of the metals were below their respective EQS limits (Table 5.3 and Table 5.4).

However, it should be noted that the introduction of additional contaminants as a result of poor manufacturing or mining of brucite (section 2.2) or during storage and transport of brucite (section 2.3) may influence ecotoxicity or compliance to the EQS.

In addition, in agreement with the worst-case dilution factor of 500 provided by Planetary, CORMIX modelling reported minimum and maximum dilution factors of 500 and 2773 respectively (section 4.2). Dilution factors >500 will decrease the risks posed by the contaminants to the aquatic organisms.

At the addition rates and concentrations proposed in this study, the trace metals in MH pose a low risk of harm to local organisms, and adverse effects on marine organisms are not anticipated following exposure.

Table 5.1 Screening with EQS using 8 kg/min MH addition rate, effluent flow of 300 l/s, and 500-fold dilution

Metals	Average concentration (g/t)	SGS pipe concentration (µg/l)	WRc pipe concentration (µg/l)	MAC EQS (µg/l)	AA EQS (µg/l)	Exceeds EQS in pipe (Yes/No)	Exceeds EQS in water after 500-fold dilution
Strontium (Sr)	78.5	18.17	34.9	NA	NA	-	-
Arsenic (As)	11	2.78	4.89	NA	25	No	No
Cadmium (Cd)	<0.2	0.05	<0.089	NA	0.2	No	No
Mercury (Hg)	<0.3	0.07	<0.13	0.07	NA	Yes	No
Lead (Pb)	4.4	1.02	1.95	14	1.3	Yes (AA)	No
Aluminium (Al)	683	158.05	303.5	1000 or 10000	NA	No	No
Cobalt (Co)	<3	0.69	<1.33	100	3	No	No
Chromium (VI) (Cr)	2	0.39	0.89	32	0.6	Yes (AA)	No
Copper (Cu)	<1	0.23	<0.44	NA	≥3.76	No	No
Iron (Fe)	3660	846.93	1626.6	NA	1000	Yes	No
Manganese (Mn)	144	33.4	64	NA	NA	-	-
Nickel (Ni)	<8	1.85	<3.55	34	8.6	No	No
Silicon (Si)	313	72.43	139.1	NA	NA	-	-
Silver (Ag)	<2	0.46	<0.89	1	0.5	Yes (AA)	No
Tin (Sn)	<20	4.63	<8.9	NA	10	No	No
Vanadium (V)	<4	0.93	<1.78	NA	100	No	No
Zinc (Zn)	<30	6.94	<13.3	NA	7.9	Yes	No
Boron (B)	45	Not reported	20	NA	7000	No	No

NA: Not applicable

Table 5.2 Screening with EQS using 8 kg/min MH addition rate, minimum night effluent flow rate of 120 l/s, and 500-fold dilution

Metals	WRc pipe concentration (µg/l)	MAC EQS (ug/l)	AA EQS (ug/l)	Exceeds EQS in pipe (Yes/No)	Exceeds EQS in water after 500-fold dilution
Arsenic	12.22	NA	25	No	No
Cadmium	<0.22	NA	0.2	Yes	No
Mercury	<0.32	0.07	NA	Yes	No
Lead	4.88	14	1.3	Yes (AA)	No
Aluminium	759	1000 or 10000	NA	No	No
Cobalt	<3.32	100	3	Yes (AA)	No
Chromium (VI)	2.22	32	0.6	Yes (AA)	No
Copper	<1.1	NA	≥3.76	No	No
Iron	4067	NA	1000	Yes	No
Nickel	<8.8	34	8.6	Yes (AA)	No
Silver	<2.22	1	0.5	Yes	No
Tin	<22.2	NA	10	Yes	No
Vanadium	<4.45	NA	100	No	No
Zinc	<33.2	NA	7.9	Yes	No
Boron	50	NA	7000	No	No

NA: Not applicable

Table 5.3 Screening with EQS using 12 kg/min MH addition rate, average daily effluent flow rate of 285 l/s, and 500-fold dilution

Metals	WRc pipe concentration (µg/l)	MAC EQS (ug/l)	AA EQS (ug/l)	Exceeds EQS (Yes/No)	Exceeds EQS in water after 500-fold dilution
Arsenic	7.7	NA	25	No	No
Cadmium	<0.14	NA	0.2	No	No
Mercury	<0.21	0.07	NA	Yes	No
Lead	3.08	14	1.3	Yes (AA)	No
Aluminium	479.2	1000 or 10000	NA	No	No
Cobalt	<2.1	100	3	No	No
Chromium (VI)	1.4	32	0.6	Yes (AA)	No

Metals	WRc pipe concentration (µg/l)	MAC EQS (ug/l)	AA EQS (ug/l)	Exceeds EQS (Yes/No)	Exceeds EQS in water after 500-fold dilution
Copper	<0.7	NA	≥3.76	No	No
Iron	2568.4	NA	1000	Yes	No
Nickel	<5.6	34	8.6	No	No
Silver	<1.4	1	0.5	Yes	No
Tin	<14	NA	10	Yes	No
Vanadium	<2.8	NA	100	No	No
Zinc	<21	NA	7.9	Yes	No
Boron	31.6	NA	7000	No	No

NA: Not applicable

Table 5.4 Screening with EQS using 12 kg/min MH addition rate, minimum night effluent flow rate of 120 l/s, and initial 500-fold dilution

Metals	WRc pipe concentration (µg/l)	MAC EQS (ug/l)	AA EQS (ug/l)	Exceeds EQS (Yes/No)	Exceeds EQS in water after 500-fold dilution
Arsenic	18.3	NA	25	No	No
Cadmium	<0.33	NA	0.2	Yes	No
Mercury	<0.5	0.07	NA	Yes	No
Lead	7.3	14	1.3	Yes (AA)	No
Aluminium	1138	1000 or 10000	No	Yes	No
Cobalt	<5	100	3	Yes (AA)	No
Chromium (VI)	3.3	32	0.6	Yes (AA)	No
Copper	<1.66	NA	≥3.76	No	No
Iron	6100	NA	1000	Yes	No
Nickel	<13.3	34	8.6	Yes (AA)	No
Silver	<3.3	1	0.5	Yes	No
Tin	<33	NA	10	Yes	No
Vanadium	<6.65	NA	100	No	No
Zinc	<50	NA	7.9	Yes	No
Boron	75.1	NA	7000	No	No

NA: Not applicable

5.2.2 Environmental risk assessment approach for MH

The environmental risk assessment approach applied here involves the comparison of the predicted environmental concentration (PEC) of MH with the predicted no-effect concentration (PNEC) of MH. The PEC is the estimated concentration of MH in the marine water body; while PNEC is the concentration of MH below which detrimental effects on marine organisms will most likely not occur. MH is not expected to pose a risk to sediment dwelling organisms based on its low potential to adsorb to sediment with a sediment-water partition coefficient (Kd) of 1.65 (ECHA, 2023).

If the PNECsaltwater is greater than the PECwater, the substance is unlikely to pose any significant risk to the environment but if the PECwater is greater than the PNECsaltwater (presuming that relevant data are available), it is likely to represent a significant risk to the environment (EC, 2003).

5.2.3 PEC Estimation or Exposure Assessment for MH

The predicted environmental concentrations (PECs) for MH were estimated based on the following information on the proposed MH dosing, the effluent discharge rate at Hayle Sewage Treatment Works (operated by SWW), and the dilution factor provided by Planetary in their report:

- Maximum MH addition rate: 12 kg/min (720 kg/hr) (revised proposal)
- Nominal effluent flow rate: 300 l/s
- Mixing zone dilution factor: 500-fold dilution
- Night-time effluent flow rate: 120 l/s
- Dry weather effluent discharge/flow rate: 228 l/s
- Average daily effluent flow rate: 285 l/s
- Full flow to treatment flow rate: 675 l/s

Based on the nominal wastewater flow rate, MH concentration in the final effluent = 12 kg/min / 300 l/s.

Therefore, MH concentration in effluent = 667 mg/l.

With a 500-fold dilution of the effluent, the concentration of MH in water body = 667 mg/l / 500.

Therefore, PEC for MH = 1.33 mg/l (1330 µg/l).

Using the full flow to treatment flow rate, MH PECwater = 0.59 mg/l (590 µg/l).

With average effluent flow rate, PECwater = 1.4 mg/l (1400 µg/l).

With dry weather discharge flow rate, PECwater = 1.75 mg/l (1750 µg/l).

For the worst case or minimum night-time flow rate, PECwater = 3.3 mg/l (3300 µg/l).

5.2.4 PNEC or Effect Assessment

The Predicted No-Effect Concentration (PNEC) is the concentration of a chemical below which adverse effects in the environmental sphere of concern are not expected to occur. Here, the PNEC for the marine environment has been derived based on the lowest toxicity endpoint from the most sensitive taxonomic group and the appropriate assessment factor (AF) based on the established EU technical guidance document (TGD) on risk assessment (EC, 2003; EC, 2008).

PNECsaltwater

The lowest acute EC_{50} of 170.6 mg/l was reported in *Daphnia magna*. Therefore, using an AF of 10 000 based on the EU TGD, the PNECsaltwater is 0.017 mg/l which will be protective of other aquatic organisms (ECHA, 2023).

The initial PNECsaltwater = 0.017 mg/l (17 µg/l) in agreement with Planetary report (pages 78 - 79 of Update 2).

However, a new PNEC was derived based on the availability of a recent study (Delacroix *et al*., 2023) that reported a 72- hour NOEC of 25 mg/l and a 72-hour EC_{50} of 82-111 mg/l for the growth rate endpoint in the sensitive model marine microalgae, *Skeletonema costatum.* However, it should be noted that the study is only available as a preprint and a revised version of this preprint is currently under peer review.

Since the short-term algal toxicity test is the most sensitive of the short-term tests available for the three trophic levels (algae, crustacean, and fish), and the NOEC reported for *S. costatum* is supported by the result of a test on a second species of algae (*R. subcapitata*), then the chronic data (NOEC of 25 mg/l) reported for MH in marine microalgae can be used for risk assessment using a lower AF of 1000 (with a NOEC value for algae, a reduced safety is used compared to when using an EC_{50}).

Based on this, new PNEC = 25/1000 = 0.025 mg/l (25 µg/l).

Planetary’s report considers the recommended AF (10,000) used for marine PNEC to be overly conservative and are looking at the possibility of providing more ecotoxicity data so that they can adopt a lower AF.

5.2.5 Risk characterisation

The estimated PECs for MH in the receiving marine water body range from 590 µg/l (for full flow to treatment flow rate) to 3300 µg/l (for the worst case or minimum night-time flow rate) and the PNEC is 25 µg/l. Based on these predicted MH concentrations and the PNEC, the risk quotient (>1) suggests a potential risk to the marine environment.

Although the risk quotient indicates a potential risk, the PNEC calculated here is highly conservative as it is calculated from chronic data available for only one taxonomic group and it is very likely that MH actually poses a lower risk to the marine organisms than the PNEC suggests. The lack of chronic toxicity data for fish, crustaceans and other marine taxonomic groups resulted in the use of a relatively high AF based solely on algal data. The availability of chronic data for other species would allow the use of a lower AF resulting in a lower risk. For example, if long-term toxicity data for crustacean, fish and two other marine taxonomic groups were to be available and if *S. costatum* was confirmed to be the most sensitive species to MH following chronic exposure, an AF of 10 would have sufficed and would have given a PNEC of 2.5 mg/l (2500 µg/l) which is almost equal to the worst-case PEC (addition rate of 12 kg/min) or higher than the PEC at an addition rate of 8 kg/min.

Therefore, the generation of chronic data for fish, crustaceans and at least two other marine taxonomic groups (molluscs, echinoderms etc.) would be recommended for a refinement of the PNEC assessment. However, it should be noted that performing chronic (i.e. long term) toxicity testing in aquatic environment could difficult due to the low solubility of MH (i.e. 12 mg/l in pure water and even lower in seawater, 8 mg/l (Yang et al., 2023)). Test duration of chronic tests range, for example, in 14-32 days for fish (OECD 210) and 21 days for *Daphnia magna* (OECD 211). To derive reliable endpoints for risk assessment, the concentration of the test substance is expected to remain within ± 20% of the nominal. For low solubility substances maintain a stable concentration in water for the entire length of the test is difficult and should be taken carefully into account in the design of the experiment.

5.3 Conclusion

The 500-fold or worst-case dilution of the effluent by the receiving Ives Bay water would bring the individual concentrations of the metals below their respective EQS, therefore, no adverse effects on the marine organisms are expected following exposure to the trace metals.

Magnesium hydroxide (MH) is of low acute toxicity to aquatic organisms. It also does not persist in the environment nor bioaccumulate in aquatic organisms.

In the risk assessment carried out for MH, a predicted no effect concentration (PNEC) of 17 µg/l was initially derived in agreement with Planetary's reported PNEC of 10 µg/l both based on short-term toxicity data using an assessment or safety factor (AF) of 10,000. However, upon the availability of chronic data on a sensitive marine microalga (*Skeletonema costatum*) from a recently published study, the PNEC was recalculated to obtain a final PNEC of 25 µg/l using an AF of 1000 (a reduced safety factor for using chronic data). Based on the predicted MH concentrations and the PNEC, the risk quotient (>1) suggests a potential risk to the marine environment.

Although the risk quotient indicates potential risk, the PNEC is open for revision, and it is very likely that MH actually poses a lower risk to marine organisms than the PNEC suggests. The lack of chronic toxicity data for fish, crustaceans and other marine taxonomic groups has resulted in the use of a relatively high AF based solely on algal data. The availability of chronic data for other species would have led to the use of a lower AF, thus resulting in a lower risk.

In addition, according to ECHA (2023), the chronic toxicity of MH to fish and crustaceans is not expected due to the low water solubility of MH, its low acute toxicity to these trophic levels and its eventual breakdown to water and magnesium which is known to be an essential nutrient in plants and animals. Taking all aspects into account (length of proposed trial, dosing concentrations, etc), it is likely that the risk to marine organisms from MH in this trial is very low.

Moreover, since the near field is about 250 m from the discharge point and the modelled zone is about 60 km by 30 km, the concentrations of MH across much of that zone will be lower due to tidal or current influences. Superficially, assuming that the concentration is proportional to the surface area, then the worst-case discharge concentration of MH (3300 ug/l) would be below the 25 ug/l PNEC after about 2.9 km from the near field, while the discharge with a MH concentration of 590 ug/l of MH after about 1.2 km.

In agreement with the worst-case dilution factor of 500 provided by Planetary, CORMIX modelling reported minimum and maximum dilution factors of 500 and 2773 respectively (section 4.2). Dilution factors >500 will decrease the risks posed by MH to the aquatic organisms.

It would be advisable to generate more ecotoxicity data on MH, especially chronic data on fish, crustaceans, and at least two other marine taxonomic groups for a refinement of the PNEC or risk assessment. Initiating monitoring programmes to determine the actual environmental concentrations of MH (due to its low water solubility) as well as the biodiversity of the marine environment within and across the near field is also recommended.

6. Review of carbon sequestration calculations

The proposed Ocean Alkalinity Enhancement (OAE) project aims to study the safety and efficacy of OAE through the addition of MH to treated effluent from the Hayle WwTW. This section reviews the feasibility of the proposed approach and robustness of the measurement, reporting and verification (MRV) procedures documenting sequestration.

6.1 Maximum Sequestration Potential

In their Carbon Footprint Calculations and Methodology, Planetary report 710g CO_2e/kg as a complete carbon footprint, or lifecycle assessment (LCA_{emiss} in Equation 1), for mineral brucite emissions, and a stoichiometric “CDR ratio” of 1.29 moles CO_2/moles MH is calculated for Hayle. This CDR ratio equates to the quantity of CO_2 in seawater that would be converted to bicarbonate and carbonate ions on complete reaction with one unit of MH, for a specified set of pH, temperature, and salinity conditions.

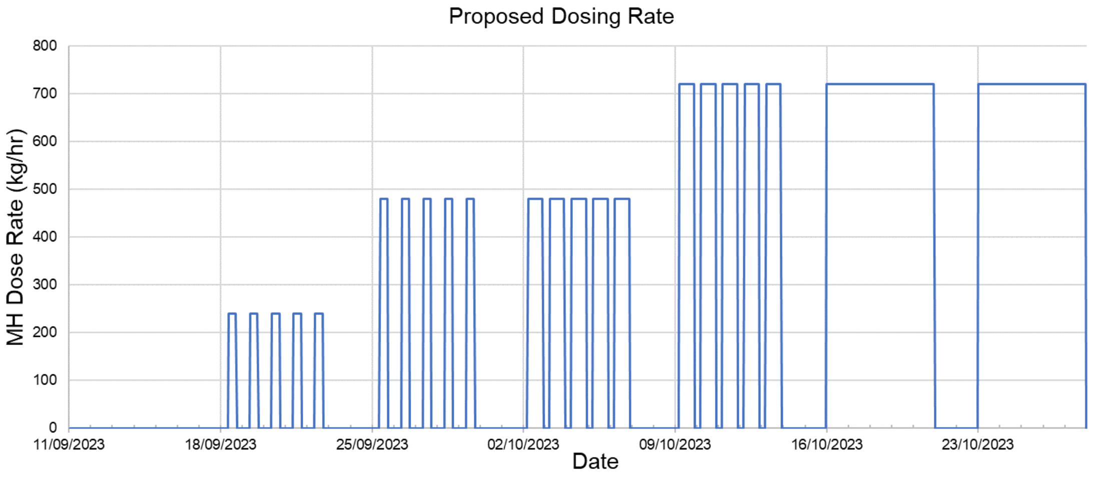
$$\mathrm{CDR_{net}} = \mathrm{CDR_{gross}} - (\mathrm{CDR_{eff}} - \mathrm{CDR_{hback}}) - \mathrm{LCA_{emiss}}$$

Equation 1

A CDR ratio of 1.29 would result in the conversion of 0.97 tCO_2/t MH from the surface ocean, assuming a CDR_{eff} of 1. This assumption requires that the mass of MH added does entirely react with CO_2 at the specified conditions and that no reversal occurs. For the mass of converted CO_2 to be considered sequestered, the CO_2 depleted seawater must also remain at the surface for long enough to fully equilibrate with the atmosphere. Each of these conditions may not be met for the entire mass of MH added, but 0.97 tCO_2/t MH may be considered the maximum value of gross carbon sequestration (CDR_{gross} in Equation 1) for the “CDR ratio” Planetary have calculated at Hayle.

At the proposed peak dosing rate of 720 kg MH/hr (scheduled for the final two weeks of the trial in Proposed Dosing Schedule (Update 3), Figure 6.1) this would result in a maximum sequestration of 16.8 tCO_2/day. Considering the reported carbon footprint for the MH, the maximum net carbon sequestration for the peak rate is 4.5 tCO_2/day.

Figure 6.1 Proposed Dosing Schedule (Update 3)



Therefore, for the stoichiometric CDR ratio stated for conditions at Hayle, CDReff-CDRhback (the factors reducing the maximum theoretical value of gross carbon sequestration, based on measurements and models of that achieved in the ocean) must be greater than or equal to 0.73 to achieve a net positive carbon offset.

In the case of future deployment prospects, the carbon footprint associated with the present sourcing of raw MH is expected to drop significantly once the MH is sourced locally rather than shipped from a Chinese mine. The resulting reduction in LCAemiss would increase CDRnet, allowing net CO_2 offset at lower CDReff values.

Many engineered CO_2 removal approaches in addition to OAE are currently being developed. The UK Government targets at least 5MtCO2 annually of these removals by 2030 in order to meet its goal of net zero by 2050 (BEIS, 2019). The global annual production of MH, of around 1Mt (Planetary Hydrogen, 2022), could meet up to 20% of this national sequestration target if used exclusively for OAE (an upper estimate calculated using the CDR ratio for Hayle, assuming a CDR_{eff} of 1 that excludes lifecycle emissions, and that enough suitable sites exist). This calculation intends to demonstrate upper limits to scalability due to current rates of MH production and represents significantly larger values than proposed by Planetary within the U.K. Planetary are investigating a range of alkalinity sources with consideration of lifecycle emissions to meet any supply chain challenges.

6.2 Permanence of Sequestration

Claims relating to the permanence of carbon sequestration resulting from the proposed OAE method are discussed here.

6.2.1 Timeframe for Equilibration

OAE aims to increase the ocean's capacity to store atmospheric CO_2. Equilibration of pCO_2 between the atmosphere and surface ocean must occur to realise this storage potential. Air-sea gas exchange, the process that facilitates this equilibration, occurs on a timescale of weeks to months (He & Tyka, 2023) and so alkalinity enhanced waters must remain within the mixed layer of the surface ocean on these timescales to allow complete equilibration and maximise CO_2 drawdown.

Planetary propose to adopt a 1-year horizon for assessing drawdown. Modelling and surveying over this length of time will adequately capture the drawdown potential, the constraint resulting in a slight underestimate of the lifetime drawdown potential.

6.2.2 Ocean Residence Time

Section 7 of Planetary's MRV document (Planetary Technologies, 2023) addresses the permanence of carbon sequestration using a mass balance to arrive at a residence time for dissolved carbon of 100,000 years. Modelling studies suggest around 90% efficiency for ocean long-term carbon storage, however beyond 1000-year timescales carbonate compensation may act to offset imbalances in alkalinity (Renforth & Henderson, 2017; Kanzaki, Planavsky, & Reinhard, 2023). Accepted literature estimates for the duration of ocean storage range from 10,000 to 100,000 years, and can be dependent on the properties of the water column (NASEM, 2022).

6.2.3 Carbonate Precipitation Reversal Risk

The precipitation of carbonate minerals from seawater involves the consumption of two moles of alkalinity per mole of carbon, resulting in a reduction in total alkalinity (TA) and pH, and shifting ocean carbonate equilibria towards CO_2 degassing to the atmosphere (Middelburg, Soetaert, & Hagens, 2020). This is a natural component of the marine carbon cycle; however, OAE has the potential to induce additional carbonate precipitation. Additional precipitation would reduce the efficiency (CDR_{eff}) of CO_2 removal from the atmosphere, or potentially result in a net loss of ocean alkalinity by triggering "runaway precipitation" (Hartmann, et al., 2023) – effectively reversing the intended process. Additional precipitation may also result in coprecipitation of trace metals which could limit sea surface productivity or potentially concentrate these metals on the seafloor affecting the benthos (Arslan, et al., 2018). Precipitation resulting from OAE must be quantified to understand the efficiency and wider effects of CDR.

Carbonate precipitation may be abiotic or biologically controlled. Spontaneous abiotic nucleation is strongly inhibited in seawater but may be encouraged by the presence of mineral particles to act as nucleation sites, and increases in TA, pH, or carbonate saturation.

In Planetary's Uncertainty Management Plan, abiotic secondary precipitation is discussed. Experimental results and carbonate system calculations have been presented to demonstrate a *Low* to *Negligible* risk of abiotic secondary precipitation. This conclusion is reached due to the low solubility of MH not allowing perturbations of TA beyond a suggested 500 μmol kg−1 threshold for precipitation, and rapid dilution mitigating local increases in pH.

Thresholds for geochemical responses such as precipitation of carbonate minerals are dictated by a range of environmental variables and cannot be unequivocally discounted (Subhas, Lehmann, & Rickaby, 2023). The persistence of undissolved MH particles within a solution supersaturated with respect to calcium carbonate, such as the ocean, can act as a nucleation surface, and would likely lead to secondary precipitation of calcium carbonate. This would cause alkalinity loss.

WRc considers there to be *a medium* risk of secondary precipitation in this manner. The reported dissolution time of greater than 33 days (allowing for chemical perturbations in the microenvironments around MH particles), and uncertainties discussed in Section 3.4 creating a moderate possibility of secondary precipitation occurring, and the potential severity of the outcome ranging from minor (reduction in CDR_{eff}) to significant (reversal of intended sequestration effect). Monitoring for carbonate precipitation and the dissolution of MH particles as part of the MRV approach is necessary to ensure a robust approach for estimating CDR.

Carbonate production in seawater is thought to be largely biologically controlled (Renforth & Henderson, 2017). Calcifying organisms such as coccolithophorids consume alkalinity and are sensitive to alterations in environmental conditions (Middelburg, Soetaert, & Hagens, 2020). The diverse adaptions of marine biota have different responses to environmental changes, and the complex interactions in these ecosystems are challenging to represent in models (Hartmann, et al., 2023).

Biocalcification and ecological responses have not been considered by Planetary in either the secondary precipitation document or carbonate system modelling. The effects of biocalcification and photosynthesis on CDR were assessed to be “small relative to existing DIC and A_T pools, and to the additional alkalinity added by the SeaOH2 process” in the publicly available Phase 1 Final Report (Planetary Hydrogen, 2022).

Thresholds for biogeochemical responses such as precipitation of carbonate minerals are dictated by a range of environmental variables and cannot be unequivocally discounted (Subhas, Lehmann, & Rickaby, 2023) but the low risk of increased precipitation in this manner has been suitably demonstrated. WRc agrees with the assessment that the magnitude of change in carbonate chemistry (following the modelled mixing and dilution) is small in comparison to seasonal variations at the dosing rates proposed by this trial. Significant perturbations of the marine ecosystem are therefore unlikely to occur in the far-field (defined by Planetary as beyond a 125m radius from the outfall). The monitoring program in the mid-field zone offers an opportunity to provide insight into these interactions.

6.3 Co-benefits

There is potential for mitigation of ocean acidification impacts near injection sites, however, ocean pH is largely restored to pre-OAE value once alkalinity-enhanced seawater has equilibrated with atmospheric CO_2 (Mongin, Baird, Lenton, Neill, & John, 2021).

Any potential ecological co-benefit of restorative impact for coral reef ecosystems discussed in the MRV document (Planetary Technologies, 2023) would be a result of enhanced calcification rates. This is a trade-off at the expense of reduced CO_2 sequestration efficiency.

6.4 Modelling

The regions modelled have been defined by Planetary as near-field, mid-field, and far-field. The near-field has been defined as the unstable area of 50m radius around the discharge points, and is discussed in detail in Section 4. The mid-field zone has been defined by the point at which the discharge plume reaches the sea surface, an annulus of 50m to 125m radius around the discharge point, and the far-field is the further 1300km^2. The effects of MH dispersal in the far-field have been modelled and submitted by Planetary (Port & Coastal Solutions, Coastal Science Ltd, 2022), and are reviewed here.

The hydrodynamic performance criteria in relation to tidal flows (Table 6.1) have been demonstrated to be satisfactory. The model omits the hydrodynamic effects of vertical mixing and wind forcing. This decision is justifiable as these are lower order effects in a well-mixed and tidally dominated area but introduces uncertainties in the calculation of air-sea CO_2 fluxes.

Table 6.1 Hydrodynamic model performance metrics

Performance criteria	Threshold	Threshold met?
Modelled WL	±0.1m or within 10% and 15% of spring and neap tidal ranges	Yes, at HW and LW. RMS of +0.12m is slightly higher than recommended 0.1.
High water (HW) and low water (LW) timing	Within 10 mins	Yes
Peak flood (PF) and peal ebb (PE) speeds	Within ±0.2m/s or within 10% and 20% of spring and neap flows.	PF and PE not calibrated for, justified by lack of appropriate data.
Peak flow directions	Within ±10°	Not calibrated for, justified by lack of appropriate data.

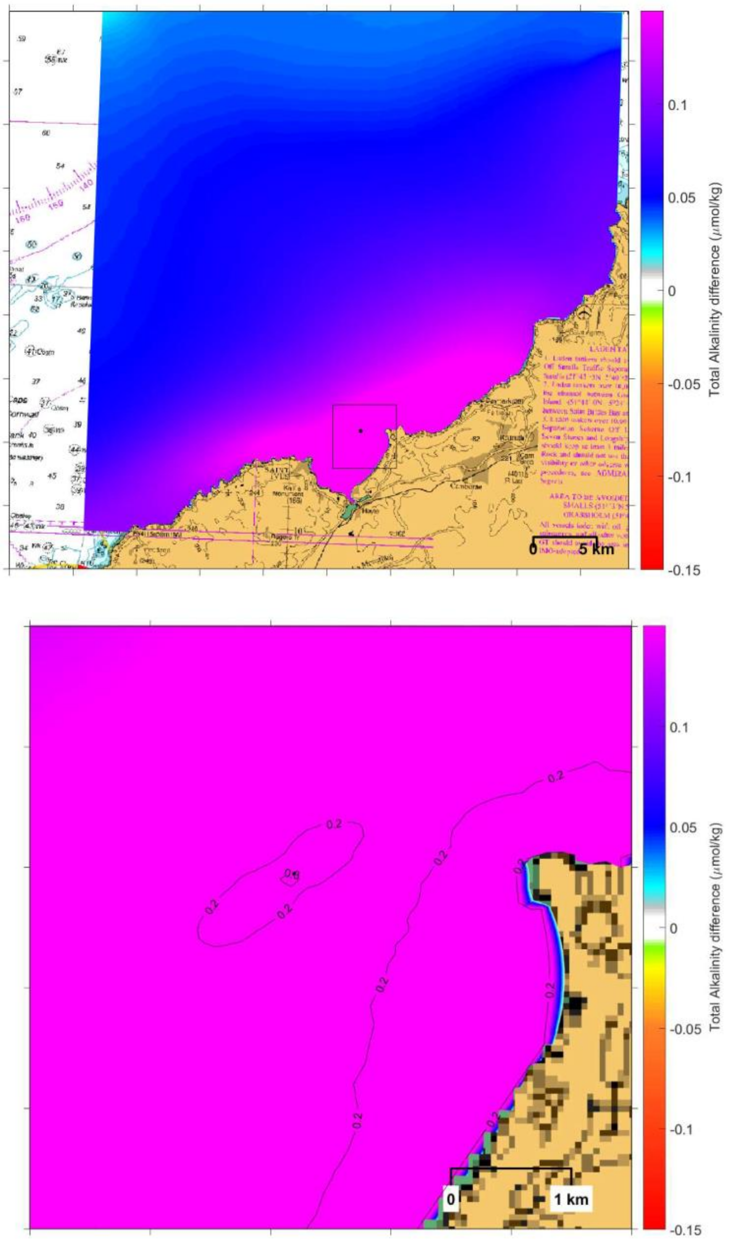
Carbon cycle modelling was carried out in the D-WAQ module (Port & Coastal Solutions, Coastal Science Ltd, 2022). Planetary have stated that the modelling reviewed here was not intended to represent the proposed trial and that an improved model is under development. The carbonate chemistry processes integrated with the module are sound, but as noted in Section 6.2.3, do not include the effects of biotic calcification or the complexity of other biogeochemical responses. Biota are an important component of air-sea CO2 flux and so the omission of their influence in the model introduces uncertainty to the total carbon flux. It is unlikely that the omission would have a significant effect on the modelled drawdown of CO2 as the rapid dilution renders the perturbation of carbonate chemistry negligible in comparison to natural background variability (Ho, et al. 2023).

The dissolution rate of the MH particles will vary with temperature and pH in reality but this is not represented in the model, as discussed in section 3.4. Overestimating the dissolution rate could lead to an overestimated CDR as the solid particles are may sink to the seafloor or be removed by grazers, and so the eventual alkalinity addition may be unable to equilibrate with the atmosphere (NASEM, 2022).

It is important to note that the dosing scenarios modelled in the far-field report are not equivalent to the most recently proposed dosing schedule. The lowest, starting rate of dosing proposed is 1920kg MH/day, close to twice that of the modelled ‘high dosing’ scenario (842kg MH/day). The peak proposed dosing rate is 17280kg MH/day.

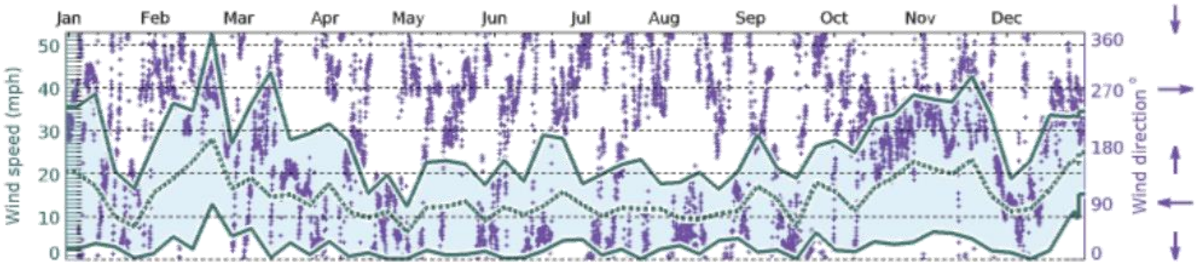
The Map plot of TA change (Figure 6.2) shows the predicted TA increase as a result of the modelled ‘high dose’ is less than 0.1 µmol/kg for the majority of the modelled far-field area. The colour scale is unclear as to the peak TA increase predicted in the far-field modelling, however the reported near-field modelling predicted a 3 µmol/kg increase at the outfall for a comparable dose. These values are significantly lower than the 500 µmol/kg benchmark for triggering secondary precipitation. As the ‘high’ dose here is 1/20th of the proposed peak dosing rate, it is worth noting that the near-field study found a 5-fold increase in dosing rate resulted in an approximate doubling of the impact on seawater chemistry directly at the outfall.

Figure 6.2 Map plot of TA change. 95th percentile TA change (relative to existing) for the addition of a high dose of MH to the existing discharge under summer conditions. (Figure 55 of Far-field Modelling Study)



The equation chosen to quantify air-sea exchange of CO2 in the model is a function of the square of wind speed and produces conservative estimates for exchange at high and low wind velocity in comparison to more complex approaches (Bell, et al., 2017). The wind velocities applied in the model for winter and summer conditions equate to 22 mph and 14 mph. These values are in line with the source (Historical wind speed at St. Ives, Figure 6.3), however the assumption of constant average values introduces uncertainty to the model given the true variability of the wind.

Figure 6.3 Historical wind speed at St. Ives, 2022 (Meteoblue.com)



The PART model employed to investigate the potential for settling MH particulates uses a reasonable settling velocity and very conservative water depth of release, in addition to not considering the effect of dissolution on settling. These assumptions produce an estimate of the peak proportion of released particulate settling on the seabed of 40% at neap tides. This equates to around 0.07g of MH per square meter of seabed of the 40km^2 stated. Results are only shown for one tidal cycle, so the possibility remains of further particulate build up for dosing schedules lasting longer than 2 weeks. Additionally, the dosing rate modelled is 750kg/day, whilst the maximum daily dosing rate proposed for the trial is 17280kg/day. It is uncertain how the PART model results would scale with the order of magnitude increase in dosing rate. Benthic visual assessments and a complementing suite of marine monitoring data proposed as part of the monitoring scope will be able to validate the assertion that build-up of MH on the seabed and chemical perturbations beyond the mid-field would be undetectable.

6.5 Measurement, reporting and verification

On the relevant timescales for MRV, proposed as 1-year for the effects of carbon sequestration, added alkalinity will be diluted beyond detectable levels for the purpose of physically monitoring CO_2 drawdown. A model-based approach is suggested as a solution to this issue, but consensus is that fit-for-purpose models are not currently available, and that comprehensive monitoring of trials is required to produce models that accurately represent alkalinity additions (Ho, et al., Monitoring, Reporting, and Verification for Ocean Alkalinity Enhancement, 2023). Planetary did not intend to quantify carbon drawdown with the current model and have stated that a validated MRV framework is in the process of being created.

Ocean alkalinity enhancement MRV should assess the additionality, leakage and durability of CDR. Additionality being the quantity of drawn-down CO_2 beyond what would have occurred without the OAE process. Leakage may be defined as the amount of CO_2 that escapes or is emitted due to the OAE process – exemplified by biogenic calcification or abiotic carbonate precipitation. The far-field modelling submitted (Port & Coastal Solutions, Coastal Science Ltd, 2022) does provide an assessment of additionality by comparison of MH addition results to existing discharge results, however the resultant CDR_{eff} values (Table 6.2) dominantly reflect the proportion of added alkalinity that was able to equilibrate with the air before passing out of the model domain, producing what are likely large underestimates of CDR potential. While the current consensus is that leakage from OAE is likely to be small to negligible, development of scientific understanding is also required in terms of capturing biochemical and geochemical responses to adequately assess leakage numerically.

Table 6.2 CDR_{eff} values based on change in carbon flux relative to existing discharge

Scenario	CDR_{eff}^{WINTER}	CDR_{eff}^{SUMMER}
158kg/day fully dissolved MH	0.73	0.35
‘Low dosing’ 158kg/day dissolved + 112kg/day particulate MH	0.67	0.30
‘High dosing’ 158kg/day dissolved + 842kg/day particulate MH	0.60	0.26

Planetary have proposed a suite of measurement approaches for sampling in the near-field at the outfall, in the mid-field mixing zone and at a similar control site that will assess the impacts on marine biota and seawater chemistry. The proposed continuous pH and turbidity monitoring adjacent to the diffusers paired with weekly to bi-weekly discrete sampling are intended to allow the standardised measurement of key carbonate system parameters, to enable the identification of risks such as carbonate precipitation or ecological disruption. The proposed weekly to bi-weekly benthic visual assessments and three dive surveys are intended to monitor the risk of MH build up at the seabed.

The sensitivity and accuracy of the proposed monitoring instruments has not been provided, but the modelled magnitude of changes in seawater chemistry are smaller than the uncertainties typically associated with these measurements. In addition, there is natural background variability in the carbonate system parameters due to wind velocity and seasonal factors. WRc therefore consider it unlikely that any true signal of alkalinity addition will be possible to resolve beyond the mixing zone (i.e. following dispersal) from measurement approaches in the environment.

An additional sampling point in far-field area to demonstrate the predicted negligible perturbations in seawater chemistry is recommended. WRc consider a weekly to bi-weekly sampling frequency adequate to provide information on the broad impacts of the weekly to bi-weekly incremental dosing stages. The proposed monitoring methods do not capture the entire diversity of biota in the environment – for the planktonic ecosystem, this could be achieved through environmental DNA samples. The proposed sampling frequency would not provide sufficient time resolution to identify trends on tidal timescales. An increased sampling frequency would be beneficial for model verification and development at these timescales. Data from the proposed monitoring schedule will allow the credibility of the carbonate modelling to be better assessed, and the benthic visual assessments and dive surveys are essential for the identification of increased secondary precipitation risk.

6.6 Conclusions

The review of carbon sequestration calculations has concluded the following key points:

- There is evidence that OAE by MH addition could be a scalable approach to CO_2 removal. The approach may be ultimately limited by the volume of MH that can be supplied.

- The current model likely underestimates the efficiency of carbon drawdown due to shortcomings such as its geographical limits. Improved models of carbon drawdown and/or less carbon intensive sources of MH could produce verifiable carbon offsets.

- The permanence of storage for OAE sequestered carbon is in the order of tens of thousands to hundreds of thousands of years.

- The proposed dose rate is higher than the dispersion modelling but is unlikely to produce perturbations of detectable scale in seawater chemistry or biogeochemical processes beyond the mid-field mixing zone. It is recommended that an additional sampling point in the far-field mixing zone is added to the monitoring plan in order verify this.

- The importance of monitoring for solid MH build-up to inform the *medium* risk of secondary precipitation through dive surveys and benthic visual assessments is emphasised.

- Accurately establishing the CDR efficiency (and therefore the ultimate viability) of this approach to CDR requires more complex models than are currently available.

- The robust measurement, reporting and verification of CO_2 removal is an ongoing scientific challenge. Data from the proposed trial would support the development of fit-for-purpose MRV models.

7. Conclusions and recommendations

7.1 Magnesium hydroxide audit

- Specify to Planetary and SWW that a change in supplier or batch of Magnesium Hydroxide (brucite) would require a full quality assurance review and audit to ensure safety and compliance of the new material. If the source of brucite is going to be through the same supply chain, WRc would recommend not using them until full quality assurance and checks have been completed to ensure material specification.

- Ensure that the Control of Substances Hazardous to Health 2002 (COSHH) Regulations are adhered to (although this may be outside of the EA's remit).

- Request evidence of the laboratories' certifications or accreditations (specifically to ISO 17025) to give confidence in the accuracy and reliability of their test results for asbestos and the characterization of magnesium hydroxide.

- It is recommended that the sample reference point be understood for when the Eurofin's Asbestos Test was completed to ensure this was taken as close to the final product specification. In addition to this, confirmation should be sought around the batch number and evidence it is the batch being trialled that was tested as no identifying number was found.

- Either gain assurance the milling at Garrison Minerals LLC is undertaken with quality control or request additional samples to be taken of the product post milling (potentially from stock being stored in Southampton) to have confidence that no contamination has occurred.

- Identify if the storage requirement stated in the Safety Data Sheet is purely for safety or a quality requirement to ensure no cross contamination or other risks.

- If the above recommendations are not satisfied, a possible mitigation may be to undertake the sampling again on the brucite that is currently being stored in Southampton by an accredited laboratory. This should be taken randomly from the brucite sacks in a controlled manner that is compliant with ISO 17025 which forms part of the laboratories quality management system.

- Planetary should not use this source of supply in the future unless a comprehensive social responsibility audit is undertaken, and the material can be fully traced back to its source.

- Planetary should not rely solely on certificates for matters pertaining to social responsibility in an industry like mining. Planetary should require copies of audit reports as a minimum and appoint a reputable company/auditor to visit the site for best practice.

- Supply agreements should have social responsibility clauses holding Planetary's direct supplier accountable for conducting adequate levels of due diligence and providing evidence of such.

- If purchasing from a mine that may be or may have been associated with asbestos, the safety protocols for asbestos management and evidence of mining safety insurance should be requested.

7.2 Wastewater treatment works permit and process

- As expected, there is no effect on the operation of the WwTW as the addition of MH takes place in the final effluent system and therefore does not affect the performance of the treatment plant.

- WRc concurs with Planetary that struvite precipitation is not anticipated.

- WRc predicts slightly lower concentrations for magnesium hydroxide in the mixing zone than the Planetary report, and that the concentrations are low compared to the trigger concentrations of SS exceeding 100 – 150 mg/l.

- WRc predicts lower pH values than Planetary report, but recognises that WRc's tool is based on equilibrium conditions, and that the literature supports the short-term pH rises predicted by Planetary.

- The impact of the dosing near to the discharge point in the bay is not expected to increase the Suspended Solids (SS) by more than a few milligrams per litre. This is a small increase compared to the SS concentration permitted in the final effluent.

- The dissolution model used in the Planetary reports does not include a temperature effect, and therefore probably overstates the expected carbon capture in winter, and possibly also in summer. The interaction with pH means that estimating the degree of reduction would require re-running the model.

- Mixing intensity may also result in the model over-predicting DR, but it is not clear from reviewing the underlying paper if this is the case, or only affects the initial stage of dissolution – in which case the DR used may be low, ignoring the initial higher dissolution rates before the steady-state DR are reached.

- The uncertainty over the temperature and mixing effects, both of which may have over-estimated the dissolution rate, mean that WRc would regard it as pragmatic to take samples from the bed near the discharge point, and radially out to the estimated end of the near/mid-field (around 200 – 250 m), to test for the potential of magnesium hydroxide accumulating in the sediment. Turbidity measurements both near the bed and in the water column will also allow for an estimation of the effect of MH particles accumulating in the near-field around the discharge point.

7.3 Magnesium hydroxide dispersion modelling audit

- The models used for this investigation, Delft2D, and CORMIX, are appropriate and have been built following recognised and accepted methodologies and data. The hydrodynamic model has not been calibrated against any field data, although ADCP data have been used to compare and verify against the results. The model performs reasonably well against the ADCP data but tends to overpredict ebb flows.

- CORMIX was used to determine how the discharge should be modelled in the hydrodynamic model. CORMIX is a relatively simple mixing model and its output is used to confirm the plume extent and mixing within a water column in the near and mid-field areas of the outfall. The CORMIX results confirmed that the discharge, with its tendency to rise to the surface and become almost fully mixed at the mid-field (~50 m from the outfall), could be represented adequately by assuming it would be fully mixed within one cell in the hydrodynamic model with its current grid resolution.

- It is noted that the hydrodynamic model tends to overpredict the ebb flows, as shown when compared to those from the ADCP data, and this would over predict the effects of dispersion and mixing. This may have implications for the water quality and dispersion modelling, although the modelling report suggests that this is not likely to be the case.

7.4 Environmental toxicology assessment

- The lowest, or worst-case, 500-fold dilution of the effluent by the receiving Ives Bay water would bring the individual concentrations of the metals below their respective EQS, therefore, potential ecotoxic effects on marine organisms are not expected.

- Magnesium hydroxide is of low acute toxicity to aquatic organisms and of low chronic toxicity to microalgae. It also does not persist in the environment nor bioaccumulate in aquatic organisms. The concentration of magnesium hydroxide below which adverse effects on marine organisms will most likely not occur (PNEC) reported in this study is relatively low and agrees with the value reported by Planetary. However, there is concern that this PNEC value may be overconservative since magnesium hydroxide is of low long-term toxicity to marine microalgae and it is also not expected to be toxic to fish and crustacean following long-term exposure. Therefore, the generation of additional chronic toxicity data on other marine species is highly recommended for a refinement of the assessment.

- Initiating monitoring programmes to determine the environmental concentrations of MH as well as the biodiversity of the marine environment within and across the near field are also recommended.

7.5 Review of carbon sequestration calculations

- There is evidence that OAE by MH addition could be a scalable approach to CO_2 removal. The approach may be ultimately limited by the volume of MH that can be supplied.

- The current model likely underestimates the efficiency of carbon drawdown due to shortcomings such as its geographical limits. Improved models of carbon drawdown and/or less carbon intensive sources of MH could produce verifiable carbon offsets.

- The permanence of storage for OAE sequestered carbon is in the order of tens of thousands to hundreds of thousands of years.

- The proposed dose rate is higher than the dispersion modelling but is unlikely to produce perturbations of detectable scale in seawater chemistry or biogeochemical processes beyond the mid-field mixing zone. It is recommended that an additional sampling point in the far field mixing zone is added to the monitoring plan in order verify this.

- The importance of monitoring for solid MH build-up to inform the *medium* risk of secondary precipitation through dive surveys and benthic visual assessments is emphasised.

- Accurately establishing the CDR efficiency (and therefore the ultimate viability) of this approach to CDR requires more complex models than are currently available.

- The robust measurement, reporting and verification of CO_2 removal is an ongoing scientific challenge. Data from the proposed trial would support the development of fit-for-purpose MRV models.

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Appendix A Evidence requested for Quality Assurance Audit

	No	Question	Response
General	**1**	Supplier Name	
	2	Factory name and address	
	3	Name and contact details of factory manager with overall accountability for the factory, its workers, operations and outputs	
	4	Number of workers on site	
	5	Number of workers in factory provided accommodation	
	6	Number of homeworkers or village workers	
	7	Provide a description of the factory including condition of construction, approx. size of all buildings on site and number of floors of highest production building	
	8	Provide a description of all that the factory sells	
	9	List the key manufacturing processes	
	10	Provide a subcontractors list	
	11	How long has Planetary been purchasing from the factory	
	12	Is the production building shared with other companies? If yes, provide a description of their activities.	
	13	How does the factory manager (listed in Q 3) mitigate the risk of bribery and corruption occurring?	
	14	Does the factory have a business license and can it be provided?	
	15	Provide the contractual agreement between the factory and Planetary (or Planetary's supplier if not directly procured)	
Labour	**16**	Is there any evidence to demonstrate that no child labour occurs at the factory (in line with Chinese working age restrictions of 16 years old)?	
	17	Is there any evidence to demonstrate that no forced labour occurs at the factory?	
	18	Is there any evidence to demonstrate that physical disciplinary actions are not undertaken?	
	19	Can evidence of the factory's accounts and employee salary payments be provided?	
	20	What is the factory's policy on overtime, is it ever forced or limited?	
	21	What is the factory's policy on maternity leave? What are the salary entitlements?	
	22	What is the minimum salary paid by the factory to its workers**?**	
	23	How often are employees able to take a day off?	
	24	Does the factory hold any workers original ID	

		documentation?	
	25	How many toilets are on site and in any dormitories?	
	26	Do workers all have written and signed terms and conditions or contracts of employment?	
	27	Are there trained first aiders on site? If yes, provide their details.	
Safety	**28**	Are there any images of the factory, external or internal? If yes, provide these.	
	29	What fire exits are present within the factory grounds and any dormitory grounds?	
	30	What flammable, corrosive or poisonous chemicals are stored on site? What are the safety procedures for them?	
	31	Are there fire alarms present? If yes, is there any evidence to demonstrate they are working?	
	32	Are any exits ever blocked or locked?	
	33	What fire fighting equipment is accessible on site?	
	34	Who is accountable for health and safety?	
	35	Are any other alarms present on site and in dormitories?	
	36	What are the fire evacuation drills?	
	37	What machines are used on site?	
	38	Is there any evidence to show the conditions of the machines, such as a maintenance report and images?	
	39	Provide product safety information on all products purchased by Planetary.	
	40	Provide boiler and generator operation licenses and service history.	
Environment	**41**	Provide environmental discharge licenses or evidence of discharge practices.	
	42	Does the factory measure its GHG emissions? If yes, can the data be provided?	
	43	What energy saving measures are taken by the factory?	
	44	Provide chemical handling process descriptions and any evidence to support safe environmental handling.	
	45	Provide evidence of air emissions processes (e.g. filters).	
	46	Who is accountable for environment management?	
	47	Provide information on waste disposal practices, such as the details of waste contractor licensing and waste logs.	
	48	Has the factory ever faced any fines or sanctions for environment control breaches?	
	49	Are pollution management procedures in place? For example, the control of effluent / wastewater. How are they documented?	
	50	Are measurements and controls in place for noise, vibration dust, fumes, odours?	

Modern Slavery	**51**	Does the factory pay for travel for migrant workers from home provinces and/or other countries? If yes, does the factory pay for return travel when a worker chooses to leave the factory's employment?	
	52	Does the factory hold fees from worker salaries as savings or similar for "safe keeping"?	
	53	Have any workers paid for their jobs via agency fees? E.g. travel costs from their home country charged by an agent, health tests, administrative fees	
	54	Who is responsible for ensuring there are no modern slavery practices on site and in the hiring of new workers?	
General Quality	**55**	Is there additional Brucite (Magnesium Hydroxide) from Garrison Minerals to be used in this trial that is not within the existing batch and therefore not subject to completed testing?	
	56	WRc to see the batch reference for this supply of Brucite.	
	57	WRc to see the laboratory accreditation for the Asbestos test on the brucite by Eurofins Reservoirs (i.e. Accredited to ISO 17025 for performing appropriate tests)	
	58	There is no batch refernece on the Eurofins Reservoirs or SGS Canada Inc to tie this back to batch of Brucite in question. Can you clarify and demonstrate these test results are from the batch that will be used as part of this trial?	
	59	WRc to see the laboratory accreditation for the characterisation on the brucite by SGS Canada Inc. (i.e. Accredited to ISO 17025 for performing appropriate tests)	
	60	WRc to see the journey of the brucite from manufacture to site and confirm the below; a. Manufactured in China (from an Asbestos Mine waste) b. Shipped to CIMBAR, Houston, Texas (undergone milling and packaged into 1 tonne bags) c. Shipped to London (FlueChem?) d. Heavy Goods Vehicle from London To Hayle WwTW	
	61	In the above question, at what points was the below analysis undertaken? For example, was this testing completed after milling at Houston, Texas. a. SGS Minerals Canada trace metals report b. Original and subsequent Asbestos Test Certificate/report	
		Note – depending on the above responses, WRc will need to understand the precautions taking place post sampling to ensure the quality during transportation and the QA process upon arrival at Hayle WwTW.	
	62	How will the material be stored at FlueChem (i.e. watertight warehouse) and what is the address for FlueChem where the material is to be stored?	

	63	WRc to see documentation for stock control and milling at CIMBAR in Houston. This should include; a. Handling and storage of all component materials (photos of storage piles and labelling) b. Processes and procedures for quality control through milling processes (ensuring no cross contamination to previous batched milling) c. Quality control checks undertaken (What quality control is in place post milling through to site with regards to the 1-tonne sacks?)	
	64	Material Safety Data Sheet; 1. It states the material should be stored with its container 'closed' when not in use. Can you demonstrate how this will happen when its stored and transported in the 1-tonne super sacks? 2. Can you state at what point the Material Data Sheet applies? Is from manufacture in China, milling at CIMBAR or another point?	
Evidence through Procedures, photos and records for the Manufacture Quality Control	**65**	1. Evidence of Raw materials/components as per below	
	66	· Details Manufacture(s)/supplier(s) of raw materials	
	67	* Specifications and tolerances	
	68	* Approved supplier list	
	69	· Goods in procedure	
	70	* Evidence showing receipt of raw goods	
	71	* QA check at time of receipt	
	72	* Checks to ensure raw goods meet specification	
	73	* Checks on measurable parameters	
	74	* Suppliers Certificate Of Conformity on delivery	
	75	* Refused delivery procedure/quarantine area	
	76	· Storage of raw materials	
	77	* Manufacturer’s requirements	
	78	* Evidence of Storage conditions	
	79	2. Quality control of manufacture	
	80	· Checks on materials before production	
	81	* Shelf life	
	82	* Batch	
	83	* Correct material	
	84	· Records of raw materials used (batch numbers)	
	85	· Mix ratios	
	86	· Manufacturing procedure specification (MPS)	
	87	* Version number	
	88	* Date issued	
	89	* Issued by	
	90	* Document control (i.e. electronic or paper based)	
	91	· Staff involved	
	92	* Qualifications	

	93	* Training records	
	94	* Evidence they’re aware of / adhere to the MPS	
	95	· QC checks	
	96	* Is it carried out by specified quality control personnel?	
	97	* Training of supervisors/QC personnel	
	98	* At which point in the manufacturing procedure are QC checks done	
	99	* Process for failed components	
	100	· Calibration of equipment	
	101	o Evidence of calibration for specific equipment used	
	102	· Traceability	
	103	* Number produced in a batch	
	104	* Batch date	
	105	* Raw materials used	
	106	* Person(s) involved in production	
	107	* QC control	
	108	* Number of components passed / failed	
	109	* Traceable on the final product	
	110	* Data storage	
	111	· Stop/start authority	
	112	3. Finished goods	
	113	· QC checks on completed goods	
	114	· Storage of finished goods	
	115	· Transportation	
	116	* Labelling	
	117	* Temperature	
	118	* Measures to prevent contamination	
	119	* Traceability	
	120	4. Staff competency	
	121	· Example of Training records specific to the manufacture of Brucite	
	122	· External training	

Appendix B Brucite Material Safety Data Sheet

GARRISON MINERALS

SAFETY DATA SHEET

Brucite
According to Federal Register / Vol.77, No. 58 / Monday, March 26, 2012 / Rules and Regulations
Revision Date: 07/20/22 Supersedes: 03/16/17 Version 2.0

SECTION 1: IDENTIFICATION

1.1 Product Identifier

Product Form:	Mixture
Product Name:	Brucite, $Mg(OH)_2$ Powder, Magnesium Hydroxide Powder
Synonyms:	Magnesium Hydroxide
1.2 Intended Use of the Product	Not Available

1.3 Name, Address, and Telephone of the Responsible Party

Company:
Garrison Minerals
11901 West 48th Ave
Wheat Ridge CO 80033
Phone: 720-389-7609

1.4 Emergency Telephone Number
Emergency Number: 720-389-7609

SECTION 2: HAZARDS IDENTIFICATION

2.1 Classification of the Substance or Mixture

Classification (GHS-US)	Not Classified

2.2 Label Elements

GHS-US Labeling	No Labeling applicable
2.3 Other Hazards	Exposure may aggravate those with pre-existing eye, skin, or respiratory conditions.
2.4 Unknown Acute Toxicity (GHS-US)	No Data Available

SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances Not applicable

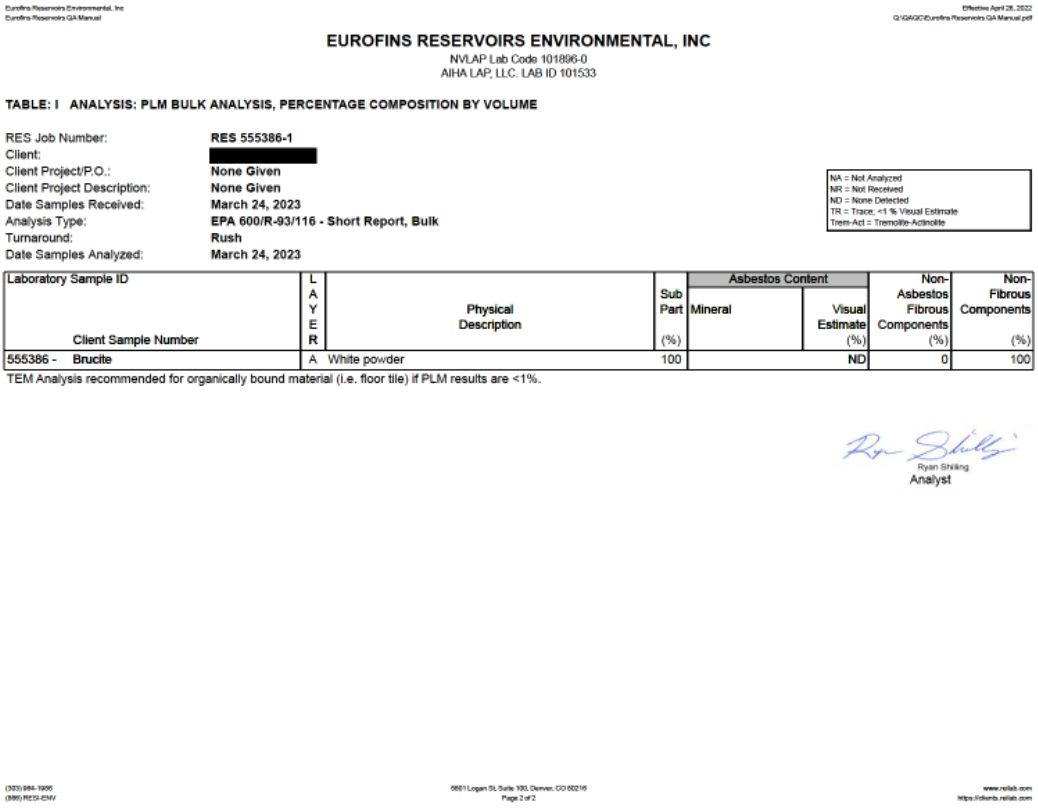
Name	Product Identifier	% (w/w)	Classification (GHS-US)
Brucite	(CAS No) 1317-43-7	100	Not Classified

Full text of H-phrases: see section 16

Page 1 of 10

w garrisonminerals.com | o 720.389.7609 | f 720.889.9470 | p 2054 Broadway Denver, CO 80205 | m PO Box 2940 Denver, CO 80201

Appendix C Eurofins Reservoirs Environmental - Asbestos Test Result



Eurofins Reservoirs Environmental, Inc
Eurofins Reservoirs QA Manual

Effective April 28, 2022
Q:\QAQC\Eurofins Reservoirs QA Manual.pdf

EUROFINS RESERVOIRS ENVIRONMENTAL, INC
NVLAP Lab Code 101896-0
AIHA LAP, LLC. LAB ID 101533

TABLE: I ANALYSIS: PLM BULK ANALYSIS, PERCENTAGE COMPOSITION BY VOLUME

RES Job Number:	**RES 555386-1**
Client:	[redacted]
Client Project/P.O.:	**None Given**
Client Project Description:	**None Given**
Date Samples Received:	**March 24, 2023**
Analysis Type:	**EPA 600/R-93/116 - Short Report, Bulk**
Turnaround:	**Rush**
Date Samples Analyzed:	**March 24, 2023**

NA = Not Analyzed
NR = Not Received
ND = None Detected
TR = Trace; <1 % Visual Estimate
Trem-Act = Tremolite-Actinolite

Laboratory Sample ID Client Sample Number	LAYER	Physical Description	Sub Part (%)	Asbestos Content: Mineral	Asbestos Content: Visual Estimate (%)	Non-Asbestos Fibrous Components (%)	Non-Fibrous Components (%)
555386 - **Brucite**	A	White powder	100		**ND**	0	100

TEM Analysis recommended for organically bound material (i.e. floor tile) if PLM results are <1%.

Ryan Shilling
Analyst

(303) 964-1986
(866) RESI-ENV

5801 Logan St. Suite 100, Denver, CO 80216
Page 2 of 2

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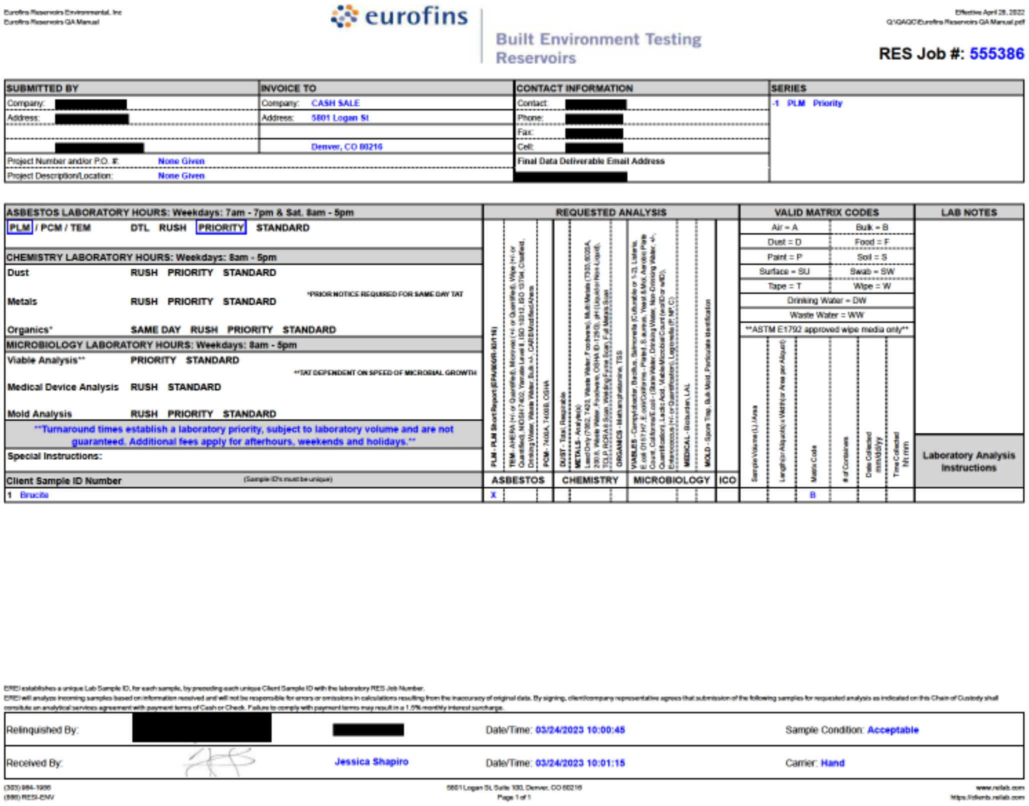
https://clients.reilab.com



Eurofins Reservoirs Environmental, Inc
Eurofins Reservoirs QA Manual

eurofins | Built Environment Testing
Reservoirs

Effective April 28, 2022
Q:\QAQC\Eurofins Reservoirs QA Manual.pdf

RES Job #: 555386

SUBMITTED BY	INVOICE TO	CONTACT INFORMATION	SERIES
Company: [redacted]	Company: CASH SALE	Contact: [redacted]	-1 PLM Priority
Address: [redacted]	Address: 5801 Logan St	Phone: [redacted]	
		Fax: [redacted]	
[redacted]	Denver, CO 80216	Cell: [redacted]	
Project Number and/or P.O. #: None Given		Final Data Deliverable Email Address	
Project Description/Location: None Given		[redacted]	

ASBESTOS LABORATORY HOURS: Weekdays: 7am - 7pm & Sat. 8am - 5pm

[✓ PLM] / PCM / TEM DTL RUSH [✓ PRIORITY] STANDARD

CHEMISTRY LABORATORY HOURS: Weekdays: 8am - 5pm

Dust	RUSH PRIORITY STANDARD
Metals	RUSH PRIORITY STANDARD
Organics*	SAME DAY RUSH PRIORITY STANDARD

*PRIOR NOTICE REQUIRED FOR SAME DAY TAT

MICROBIOLOGY LABORATORY HOURS: Weekdays: 8am - 5pm

Viable Analysis**	PRIORITY STANDARD
Medical Device Analysis	RUSH STANDARD
Mold Analysis	RUSH PRIORITY STANDARD

**TAT DEPENDENT ON SPEED OF MICROBIAL GROWTH

"Turnaround times establish a laboratory priority, subject to laboratory volume and are not guaranteed. Additional fees apply for afterhours, weekends and holidays."

Special Instructions:

REQUESTED ANALYSIS

ASBESTOS	**PLM** - PLM Short Report (EPA/600/R-93/116)
	TEM - AHERA (+/- or Quantified), Microvac (+/- or Quantified), Wipe (+/- or Quantified), NIOSH 7402, Yamate Level II, ISO 10312, ISO 13794, Chatfield, Drinking Water, Waste Water, Bulk +/-, CARB/Modified Ahera
	PCM - 7400A, 7400B, OSHA
CHEMISTRY	**DUST** - Total, Respirable
	METALS - Analyte(s) Lead Only (7082, 7420, Waste Water, Foodware), Multi Metals (7303, 6020A, 200.8, Waste Water, Foodware, OSHA ID-125G), pH (Liquid or Non-Liquid), TCLP, RCRA 8 Scan, Welding Fume Scan, Full Metals Scan
	ORGANICS - Methamphetamine, TSS
MICROBIOLOGY	**VIABLES** - Campylobacter, Bacillus, Salmonella (Culturable or 1-2), Listeria, E.coli O157:H7, E.coli/Coliforms - Plated, S.aureus, Yeast & Mol, Aerobic Plate Count, Coliforms/E.coli - (State Water, Drinking Water, Non-Drinking Water, +/-, Quantification), Lactic Acid, Viable Microbial Count (w/o ID or w/ID), Enterococcus (+/- or Quantification), Legionella (P, NP, C)
	MEDICAL - Bioburden, LAL
	MOLD - Spore Trap, Bulk Mold, Particulate Identification
ICO	

VALID MATRIX CODES

Air = A	Bulk = B
Dust = D	Food = F
Paint = P	Soil = S
Surface = SU	Swab = SW
Tape = T	Wipe = W
Drinking Water = DW	
Waste Water = WW	

ASTM E1792 approved wipe media only

LAB NOTES

Client Sample ID Number (Sample ID's must be unique)	PLM	TEM	PCM	DUST	METALS	ORGANICS	VIABLES	MEDICAL	MOLD	ICO	Sample Volume (L) /Area	Length(or Aliquots) x Width(or Area per Aliquot)	Matrix Code	# of Containers	Date Collected mm/dd/yy	Time Collected hh:mm	Laboratory Analysis Instructions
1 Brucite	X												B				

EREI establishes a unique Lab Sample ID, for each sample, by preceding each unique Client Sample ID with the laboratory RES Job Number.
EREI will analyze incoming samples based on information received and will not be responsible for errors or omissions in calculations resulting from the inaccuracy of original data. By signing, client/company representative agrees that submission of the following samples for requested analysis as indicated on this Chain of Custody shall constitute an analytical services agreement with payment terms of Cash or Check. Failure to comply with payment terms may result in a 1.5% monthly interest surcharge.

Relinquished By:	[redacted]	[redacted]	Date/Time: 03/24/2023 10:00:45	Sample Condition: Acceptable
Received By:		Jessica Shapiro	Date/Time: 03/24/2023 10:01:15	Carrier: Hand

(303) 964-1986
(866) RESI-ENV

5801 Logan St, Suite 100, Denver, CO 80216
Page 1 of 1

www.reilab.com
https://clients.reilab.com

United States Department of Commerce
National Institute of Standards and Technology

Certificate of Accreditation to ISO/IEC 17025:2017

NVLAP LAB CODE: 101896-0

Eurofins Reservoirs Environmental Inc.
Arvada, CO

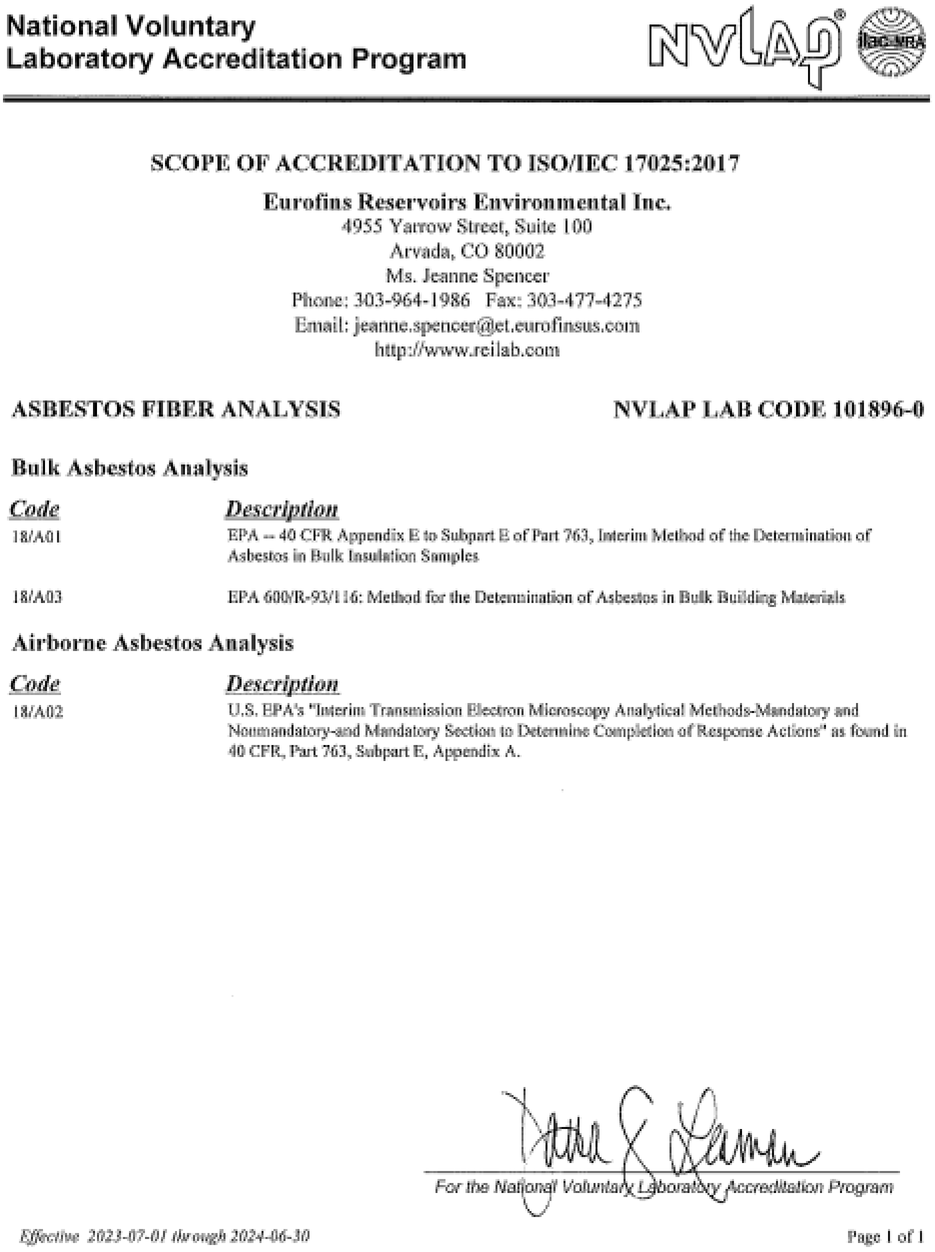
is accredited by the National Voluntary Laboratory Accreditation Program for specific services, listed on the Scope of Accreditation, for:

Asbestos Fiber Analysis

This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2017. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer to joint ISO-ILAC-IAF Communique dated January 2009).

2023-07-01 through 2024-06-30
Effective Dates

For the National Voluntary Laboratory Accreditation Program



National Voluntary
Laboratory Accreditation Program

SCOPE OF ACCREDITATION TO ISO/IEC 17025:2017

Eurofins Reservoirs Environmental Inc.
4955 Yarrow Street, Suite 100
Arvada, CO 80002
Ms. Jeanne Spencer
Phone: 303-964-1986   Fax: 303-477-4275
Email: jeanne.spencer@et.eurofinsus.com
http://www.reilab.com

ASBESTOS FIBER ANALYSIS **NVLAP LAB CODE 101896-0**

Bulk Asbestos Analysis

Code	***Description***
18/A01	EPA -- 40 CFR Appendix E to Subpart E of Part 763, Interim Method of the Determination of Asbestos in Bulk Insulation Samples
18/A03	EPA 600/R-93/116: Method for the Determination of Asbestos in Bulk Building Materials

Airborne Asbestos Analysis

Code	***Description***
18/A02	U.S. EPA's "Interim Transmission Electron Microscopy Analytical Methods-Mandatory and Nonmandatory-and Mandatory Section to Determine Completion of Response Actions" as found in 40 CFR, Part 763, Subpart E, Appendix A.

For the National Voluntary Laboratory Accreditation Program

Effective 2023-07-01 through 2024-06-30

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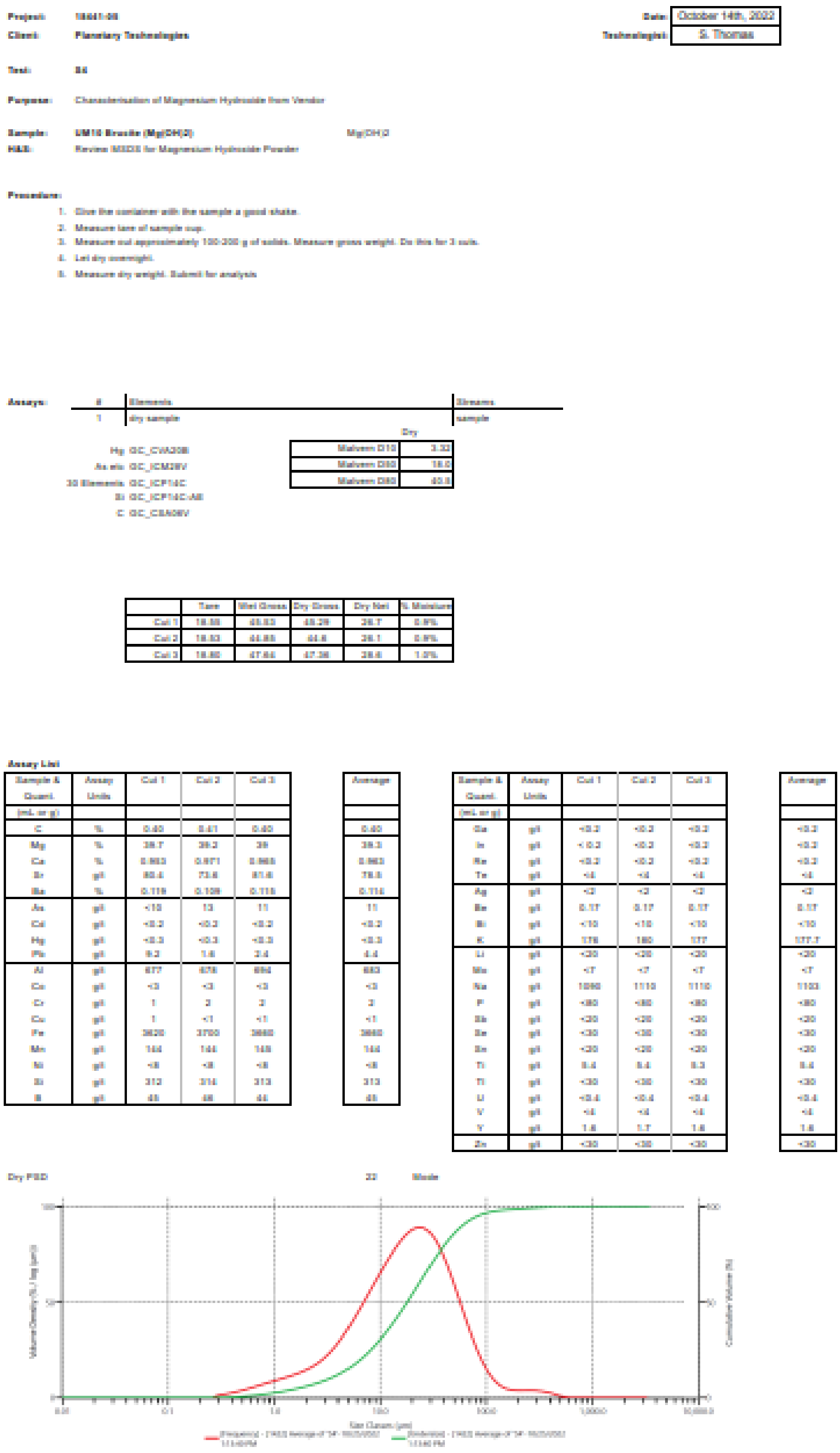
Appendix D SGS Natural Resources – Characterisation of Brucite



Project: [illegible]
Client: **Planetary Technologies**
Date: October 14th, 2022
Technologist: S. Thomas

Test: [illegible]

Purpose: Characterisation of Magnesium Hydroxide from Vendor

Sample: **UM10 Brucite (Mg(OH)2)** Mg(OH)2
H&S: Review MSDS for Magnesium Hydroxide Powder

Procedure:

1. Give the container with the sample a good shake.
2. Measure tare of sample cup.
3. Measure out approximately 100-200 g of solids. Measure gross weight. Do this for 3 cuts.
4. Let dry overnight.
5. Measure dry weight. Submit for analysis

Assays:

Assay List

Dry PSD

TESTING AND CALIBRATION LABORATORY ACCREDITATION PROGRAM (LAP)

Scope of Accreditation

Legal Name of Accredited Laboratory:	**SGS CANADA INC. – NATURAL RESOURCES – MINERALS – LAKEFIELD**
Location Name or Operating as (if applicable):	**LAKEFIELD**
Contact Name:	Valerie Kuch
Address:	P.O. Box 4300, 185 Concession Street Lakefield, ON K0L 2H0
Telephone:	705-761-6854
Website:	www.sgs.ca
Email:	Valerie.kuch@sgs.com

SCC File Number:	15254
Accreditation Standard(s):	ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories
Fields of Testing:	Chemical/Physical
Program Specialty Area:	Mineral Analysis
Initial Accreditation:	1995-03-06
Most Recent Accreditation:	2023-07-07
Accreditation Valid to:	2027-03-06

SCC Group Accreditation:
This laboratory is a part of a Group Accreditation with the following facilities in accordance with SCC's policy on Group Accreditation documented in the Accreditation Services Accreditation Program Overview.

- 15919 – SGS CANADA INC. - NATURAL RESOUCES - MINERALS – BURNABY
- 151001 – SGS CANADA INC. - NATURAL RESOUCES - MINERALS – DELTA
- 151041 – SGS CANADA INC. - NATURAL RESOUCES - MINERALS – COCHRANE
- 15745 – SGS CANADA INC. – NATURAL RESOUCES – MINERALS – RED LAKE

The physical sample preparation involving accredited test methods for Minerals Analysis as listed on the scope of accreditation may be performed at the SGS CANADA INC. - NATURAL RESOUCES -

Page **1** of **7** | ASB_JA_LAP-Scope-Template_v8_2023-02-13 Canada

Appendix E Minimum questions to be answered in a social responsibility audit

E1 General

1. Supplier Name

2. Factory name and address

3. Name and contact details of factory manager with overall accountability for the factory, its workers, operations and outputs

4. Number of workers on site

5. Number of workers in factory provided accommodation

6. Number of homeworkers or village workers

7. Provide a description of the factory including condition of construction, approx. size of all buildings on site and number of floors of highest production building

8. Provide a description of all that the factory sells

9. List the key manufacturing processes

10. Provide a subcontractors list

11. How long has Planetary been purchasing from the factory?

12. Is the production building shared with other companies? If yes, provide a description of their activities.

13. How does the factory manager (listed in Q 3) mitigate the risk of bribery and corruption occurring?

14. Does the factory have a business licence, and can it be provided?

15. Provide the contractual agreement between the factory and Planetary (or Planetary's supplier if not directly procured).

E2 Labour

16. Is there any evidence to demonstrate that no child labour occurs at the factory (in line with Chinese working age restrictions of 16 years old)?

17. Is there any evidence to demonstrate that no forced labour occurs at the factory?

18. Is there any evidence to demonstrate that physical disciplinary actions are not undertaken?

19. Can evidence of the factory's accounts and employee salary payments be provided?

20. What is the factory's policy on overtime, is it ever forced or limited?

21. What is the factory's policy on maternity leave? What are the salary entitlements?

22. What is the minimum salary paid by the factory to its workers?

23. How often are employees able to take a day off?

24. Does the factory hold any workers original ID documentation?

25. How many toilets are on site and in any dormitories?

26. Do workers all have written and signed terms and conditions or contracts of employment?

27. Are there trained first aiders on site? If yes, provide their details.

E3 Safety

28. Are there any images of the factory, external or internal? If yes, provide these.

29. What fire exits are present within the factory grounds and any dormitory grounds?

30. What flammable, corrosive or poisonous chemicals are stored on site? What are the safety procedures for them?

31. Are there fire alarms present? If yes, is there any evidence to demonstrate they are working?

32. Are any exits ever blocked or locked?

33. What fire fighting equipment is accessible on site?

34. Who is accountable for health and safety?

35. Are any other alarms present on site and in dormitories?

36. What are the fire evacuation drills?

37. What machines are used on site?

38. Is there any evidence to show the conditions of the machines, such as a maintenance report and images?

39. Provide product safety information on all products purchased by Planetary.

40. Provide boiler and generator operation licenses and service history.

E4 Environment

41. Provide environmental discharge licenses or evidence of discharge practices.

42. Does the factory measure its GHG emissions? If yes, can the data be provided?

43. What energy saving measures are taken by the factory?

44. Provide chemical handling process descriptions and any evidence to support safe environmental handling.

45. Provide evidence of air emissions processes (e.g. filters).

46. Who is accountable for environment management?

47. Provide information on waste disposal practices, such as the details of waste contractor licensing and waste logs.

48. Has the factory ever faced any fines or sanctions for environment control breaches?

49. Are pollution management procedures in place? For example, the control of effluent / wastewater. How are they documented?

50. Are measurements and controls in place for noise, vibration dust, fumes, odours?

E5 Modern slavery

51. Does the factory pay for travel for migrant workers from home provinces and/or other countries? If yes, does the factory pay for return travel when a worker chooses to leave the factory's employment?

52. Does the factory hold fees from worker salaries as savings or similar for "safe keeping"?

53. Have any workers paid for their jobs via agency fees? E.g. travel costs from their home country charged by an agent, health tests, administrative fees.

54. Who is responsible for ensuring there are no modern slavery practices on site and in the hiring of new workers?

Appendix F Response to batch numbering

Exhibit 4 - Bill of Lading from UMP for shipment of bulk break brucite from China to US

CODE NAME: "CONGENBILL", EDITION 1994

BILL OF LADING B/L NO. :SOKFCNYK2107001

TO BE USED WITH CHARTER-PARTIES

Shipper
[redacted]
[redacted]
ZHONGSHAN DISTRICT,DALIAN,CHINA
[redacted]

Consignee
UNITED MINERALS PROPERTIES INC.
ADDRESS: 49 JACKSON LAKE ROAD,
STE O CHATSWORTH, GEORGIA 30705 U.S.A.
TELEPHONE 770-387-0319 FAX 770-607-3799

Notify address
UNITED MINERALS PROPERTIES INC.
ADDRESS: 49 JACKSON LAKE ROAD,
STE O CHATSWORTH, GEORGIA 30705 U.S.A.
TELEPHONE 770-387-0319 FAX 770-607-3799

Vessel KIRAN AFRICA	Port of loading BAYUQUAN,CHINA
Port of discharge NEW ORLEANS,USA	

ORIGINAL

Shipper's description of goods		Gross weight	Measurement
N/M	COMMODITY: RAW BRUCITE PACKING:IN BULK SIZE:10-80MM	SAID TO WEIGH G.W.:5997.260MT N.W.5997.260MT	

FREIGHT PAYABLE AS PER CHARTER PARTY
MASTER'S REMARS QUALITY,QUANTITY AS PER SHORE FIGURE / SHIPPER'S DECLARATION
SAID TO WEIGHT

TOTAL: FIVE THOUSAND NINE HUNDRED NINTY-SEVEN POINT TWO SIX TONS ONLY.

(of which NIL on deck at shipper's risk; the carrier not being responsible for loss or damage howsoever arising)

Freight payable as per
CHARTER-PARTY DATED ....

FREIGHT ADVANCE
Received on account of freight

Time used for loading .... days .... hours.

SHIPPED at the Port of Loading in apparent good order and condition on board the vessel for carriage to the Port of Discharge or so near thereto as she may safely get the goods specified above.
Weight, measure, quality, quantity, condition, contents and value unknown.
IN WITNESS whereof the Master or Agent of the said Vessel has signed the number of bills of lading indicated below all of this tenor and date, any one of which being accomplished the others shall be void.

FOR CONDITIONS OF CARRIAGE SEE OVERLEAF

22 JUL 2021

Freight payable at	Place and date of issue BAYUQUAN ,CHINA JUL 22, 2021
Number of original Bs/L THREE	Signature AS AGENT FOR AND ON BEHALF OF THE MASTER ŞENGÜL MUSTAFA

AGENCY COMPANY LIMITED

AS AGENT

Proprietary and Confidential Page | 29 © Planetary Technologies, 2023

Appendix G CIMBAR ISO 9001 Certificate

ADVANTAGE ™
INTERNATIONAL REGISTRAR

ISO 9001:2015
CERTIFICATE OF REGISTRATION

This is to certify that

CIMBAR Performance Minerals

14047 Ind. Rd.
Houston, TX 77015 USA

has successfully been assessed and found to conform with the ISO 9001:2015 quality management system standard.

The scope of this registration includes:

Supply of various minerals including barium sulfate, magnesium hydroxide, and talc

Date of Registration: February 10, 2022
Date of Expiration: February 09, 2025
Date issued/revised : March 11, 2022
(Registered Since: February 10, 2022)

Certificate No. A-973-04

Steve Barfoot, President
Advantage International Registrar, Inc.

463 Captains Circle, Destin, Florida 32541-5307 USA
(Form No. AI 097 ISO 9001-09 Multi Site Registration, Page 7 of 8, www.advantageregistrar.com, Tele: (919) 846-6964)