IMPERIAL

# Business Development 2 (Supply Chain)

CCUS Innovation 2.0

Key Knowledge Deliverable 5.2

October 2024

**Key Knowledge Deliverable Cover Sheet**

This Key Knowledge Deliverable (KKD) has been produced by Imperial College London as part of the Department for Energy Security and Net Zero £1bn Net Zero Innovation Portfolio (NZIP) - CCUS Innovation 2.0 programme. The document is reflective of the status of the project at the time of writing. The material presented could have been subject to change as the project matured. These documents should not be considered a full representation of the final project.

**Project Description**

This project seeks to further develop and scale a new carbon sequestration process which transforms waste CO2 gas from industrial facilities into valuable construction products. Sequestered CO2 through this process is cheaper than conventional approaches that rely on purification, liquification and offshore or geological storage. The CO2 is stored in the form of a stable mineral which ensures they will be no leakage over time.

The patent-pending technology involves taking globally abundant magnesium silicate minerals and splitting this into magnesia and silica components. Through simple chemical processing two products of high purity are created: a) an amorphous silica that can be used as supplementary cementitious material (SCM) to facilitate low-carbon concrete and b) a concentrated magnesium solution in which CO2 from industrial flues can be sequestered to produce other construction materials.

This CCUS Innovation 2.0 award will be used to increase our technology and commercial readiness level by de-risking and facilitating the development of a pilot facility, in order to demonstrate that the technology is economically viable and deployable at scale.

**Description of KKD**

Report detailing business development activities in this quarter of the project, including: business opportunities, partnerships, and pilot and demonstration projects. Particular focus on supply chain, exploring possible geographies and embodiments of the technology to minimise transport costs and access other markets (in the short- and long-term).

**KKDs to be released in full**

- D3.4 – Concrete Trials 3
- D4.4 – Product Optimisation 2

**KKDs to be released after redactions**

- D1.1 – Flue Gas Recovery and Testing 1
- D1.2 – Dissolution Procurement
- D1.3 – Dissolution Operation
- D1.4 – Flue Gas Recovery and Testing 2 & Carbonation Procurement
- D1.5 – Carbonation Operation
- D2.3 – Reagent Regeneration Procurement
- D2.4 – Reagent Regeneration Operation
- D3.2 – Concrete Trials 1
- D3.3 – Concrete Trials 2
- D4.2 – Process Optimisation
- D4.3 – Product Optimisation 1
- D5.2 – Business Development 2 (Supply Chain)
- D5.3 – Business Development 3 (Business Planning)
- D5.4 - Business Development 4 (Commercial Readiness)
- D6.1 – Year 1 Report
- D6.2 – Year 2 Report

Any enquiries regarding this publication should be sent to us at:
nzip@energysecurity.gov.uk

# Contents

# Supply Chain Analysis

## Introduction

This report details the findings from interactions with predominant European suppliers of Olivine. Approximate quotes on bulk price and volumes available have been fed through into subsequent techno-economic analyses (TEA), incorporating scenario and sensitivity analyses. Where appropriate, reasonable assumptions have been made to complete the TEA and these are detailed.

## Olivine supply

**Sibelco (Åheim, Norway):**

- Price: €20 / t ex. quarry (£17.06)
- Supply:
  - Current production ~2 Mt per year
  - Current capacity ~5 Mt per year
  - Future max. capacity 12-15 Mt per year (limited by space around the site for processing and distribution infrastructure)
- Quality: ~6% Mg substitution with Fe, ie $(Mg_{0.94}Fe_{0.06})_2SiO_4$

**Grecian Magnesite (Chalkidiki, Greece):**

- Price: $19 / t ex. quarry (£15.05)
- Supply:
  - Current production ~1 Mt per year (as a by-product from magnesite extraction)
  - Historical stockpiles ~100 Mt (est.)
- Quality: ~4% Mg substitution with Fe, ie $(Mg_{0.96}Fe_{0.04})_2SiO_4$

## Olivine Pricing Considerations

When considering the total cost of olivine as an input for this carbon mineralisation project, there are several aspects to consider:

- Raw material price (ex. quarry)
  - See above

- Processing
    - Predominantly grinding and milling
    - Preferable to do at point of use, rather than quarry as bulk shipping of ~200 mm rock ex. quarry is easier and cheaper than powder
    - Sibelco sell limited quantities of powdered olivine (100 µm) at €44 / t, suggesting €15-20 (£12.80-17.06) processing costs per tonne.
- Transport
    - Shipping £0.0020 / t / nautical mile
    - Rail £0.0412 / t / mile
    - Road £0.1236 / t / mile

https://thundersaidenergy.com/downloads/bulk-shipping-cost-breakdown/

https://www.rsilogistics.com/blog/comparing-the-costs-of-rail-shipping-vs-truck/

# Olivine Procurement Scenarios

**Figure 1 Map of key locations for two olivine procurement scenarios**

**Table 1 Comparison of two olivine procurement scenarios**

| | Scenario 1 | Scenario 2 |
|---|---|---|
| Olivine Source | Sibelco, Åheim | Grecian Magnesite, Chalkidiki |
| Olivine Cost | £17.06 / t | £15.05 / t |
| Transport to port | 0 km (£0.00 / t) | 0 km (£0.00 / t) |
| Shipping to UK | 749 nm (£1.50 / t) | 3096 nm (£6.19 / t) |
| Road transport | 114 mi (£14.09 / t) | 74 mi (£9.14 / t) |
| Processing | £15 / t | £15 / t |
| Total cost / t | £47.65 / t | £45.38 / t |
| Quantity raw material (t) for 1t Mg2SiO4 equivalent | 1 / 0.94 = 1.064 t | 1 / 0.96 = 1.042 t |
| Total cost | £50.69 | £47.27 |

# Assumptions for Techno-Economic Analysis

**CO2 Pricing and Free Allowances**

We have assumed that the CO2 price in the UK Emissions Trading Scheme (ETS) will increase over time as fewer Allowances are available.

In line with Government projections, we have assumed that the ETS price is established at £85/t in 2026 (once the markets and trading systems are established) and grows steadily at £5/t per year until it reaches £120/t in 2033. This plateau reflects the expected full cost of CCS (ie the revenue generated from one Allowance, spent by the Government, achieves 1 t of carbon removal - resulting in a net zero economy).

At the same time the Cross-Border Adjustment Mechanism (CBAM) will reduce free allowances as shown in the orange line below. The combination of increasing CO2 price and reducing free allowances increases the CO2 cost per tonne of product. This is summarised in Figure 2.

**Other Assumptions**

**Table 2 A summary of other assumptions used in subsequent techno-economic analysis.**

| Variable | Assumption | Reasoning |
|---|---|---|
| Price of Olivine | £50 / t | A conservative assumption, based on the analysis above. |
| Inflation | 0% | Inflation is ignored for the purpose of this analysis and all costs are in 2024 £s |

# Techno-Economic Analysis – Base Case

Figure 4 [Redacted] below sets out a “base case” for the techno-economic analysis. This uses 2030 prices, as the earliest likely date at which the technology could be widely deployed at large scale (factoring in de-risking, signing commercial agreement and plant design and build).

Using a conservative olivine price of £50 per tonne, based on the previous analysis in this document, processing one tonne of flue gas CO2 costs £196.02 and generates £516.44 in revenue. This equates to an EBITDA of £235.31 once the license fee and fixed costs are accounted for - a margin of 45.6%. This is significantly higher that the target minimum of 35% to justify the cost of capital.

# Sensitivity Analysis – Olivine Price

It remains that different geographical deployment of the process, leading to variations in olivine price, is one of the greatest uncertainties in the techno-economic analysis of the process.

Table 3 below explores the sensitivity of the financial viability of the process to the cost of olivine.

In this analysis, the cheapest olivine price of £30/t is approximately representative of a “no transport” case, whereby the mineralisation process is located directly alongside the quarry, so the only costs are purchase of the raw material, and grinding/milling.

The most expensive case of £80/t is representative of a case where significantly more road transport might be required (eg to an isolated emitting facility).

It is only at £80/t of olivine, that the EBITDA margin first drops below the required 35% to justify cost of capital.

**Table 3 Summary of the effect of olivine price on EBITDA margin.**

| Olivine Price (£/t) | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EBITDA Margin (%) | 52.7 | 50.9 | 49.1 | 47.3 | 45.6 | 43.8 | 42.0 | 40.2 | 38.4 | 36.7 | 34.9 |

# Conclusions

The work conducted in this study demonstrates that:

- Olivine suitable for this carbon mineralisation process can be sourced from multiple quarries across Europe for use locally, or shipping to the UK.

- Sufficient capacity exists for the short-term pilots and scaling of the mineralisation process, but further capacity would need to be built up to maximise the long-term CO2 mitigation potential of the technology.

- Olivine can be affordably supplied from either Åheim or Chalkidiki to a UK-based pilot or industrial pilot facility. The effects of transport on the emissions assessment of the carbon mineralisation process will need to be considered separately.

Within the current set of modelling assumptions, the mineralisation process is economically viable provided that olivine can be sourced, delivered and milled for less than £80 per tonne.

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