

Bauxite Residue CO₂ Mineral Sequestration Assessment

Ab Rijkeboer¹, Carl Firman², David Cochrane³ and Ken Evans⁴

1. Director/Consultant

Rinalco, Wassenaar, Netherlands

2. Sustainability Program Manager

3. Independent Consultant

Bunbury, Western Australia

4. Consultant

International Aluminium Institute, London, United Kingdom

Corresponding author: ab@rinalco.com

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Abstract

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Since the start of the century, bauxite residue has received re-occurring attention as a potential material for carbon capture and storage. While several studies have explored this possibility, a comprehensive evaluation of the underlying chemistry, technical implications and economic viability for the alumina industry has been lacking. This paper, commissioned by the International Aluminium Institute, addresses these aspects, particularly in the context of securing carbon credits to offset emissions penalties. A typical bauxite residue mineralises approximately 12 kg CO₂ per tonne of dry bauxite residue solids (BR), equating to about 1.5 % of an alumina refinery's carbon footprint. A review of the chemistry of CO₂ capture and CO₂ mineral sequestration shows that typically two-thirds of the CO₂ initially absorbed is not mineralised and cannot be mineralised economically, creating a two-fold problem for alumina refiners. Firstly, two-thirds of the flue gas compression energy is wasted and secondly, the heavily carbonated residue liquor cannot be returned to the Bayer process untreated. The Scope 2 CO₂ emissions associated with compression energy consume a substantial fraction of the amount of CO₂ mineralised. Even without considering Scope 2 emissions, both the operating cost and the capital cost would be prohibitive on their own at the commonly used carbon credit projections at or around 100 USD/t CO₂. A carbon credit value of at least 700 USD/t CO₂ is required for the economics to break even. More viable opportunities exist in carbonating lime waste products separate from the residue. The paper discusses important aspects of the chemistry, such as pH rebound, chemical soda loss recovery potential, release of fluoride from tri-calcium aluminate, and operating preferably under reduced carbonation reactor operating pressure and reduced liquor/solids ratio.

Keywords: Bauxite residue, Carbonation, CO₂ storage, Carbon credits, Economics.

1. Introduction

Contacting bauxite residue with CO₂ has been the subject of various studies over the past few decades. In some cases, and in two PhD studies, the primary objective was assessing the potential contribution to the effort of reducing global warming [1–3]. In other studies, this was a secondary objective with the main focus being e.g. residue neutralisation [4], more efficient revegetation [5], chemical soda loss recovery [6] or metals recovery [7]. Alcoa had operated a bauxite residue carbonation unit on an industrial scale at Kwinana from 2008 for a few years using CO₂ rich waste gas from a nearby ammonia plant [8]. This was done to improve residue disposal management, while recognising the benefit of reducing the carbon impact of the operation on the climate.

It is widely recognised that bauxite residue can capture and mineralise CO₂. However, the studies published so far present only a fragmented picture. No conclusions have been drawn yet if bauxite residue carbonation is a viable proposition. The alumina industry has embarked on a program of

decarbonisation initiatives. It is of interest to the industry to know the impact of bauxite residue carbonation within the overall scheme of initiatives and if indeed bauxite residue carbonation is economically feasible in the first place. The International Aluminium Institute (IAI) commissioned a study to provide answers to these questions; this paper summarises the main conclusions from this study.

Understanding the carbonation chemistry is of crucial importance, as it is the basis for establishing (a) the quantity of CO₂ being captured, (b) the quantity of CO₂ being mineralised, (c) the key carbonation process design criteria and (d) any potential effects there may be on the Bayer process. These factors ultimately determine the cost incurred per net tonne of CO₂ mineralised, being the difference between the amount of CO₂ permanently stored in the residue and the amount of CO₂ emitted to the atmosphere due to the effort to accomplish this. The potential economic rewards are the carbon credits obtained.

2. Carbon Credits

Carbon credits can only be claimed when certain conditions are met according to the certification requirements in the applicable country. Carbon credits trading has been established in many economies around the globe, although structure and implementation is not uniform. Schemes vary between being voluntary and being compliance-based. The schemes in the EU and in Australia are compliance-based and are amongst the most developed schemes in the world. Furthermore, with the EU and Australia having well established alumina production facilities, the focus on certification requirements has been directed to those regions in the present study.

In the EU, legislation exists for geological storage of CO₂ but this concerns underground storage [11]. Legislation is under development for ground level storage, but the proposals so far are focused on agricultural and forestry projects and do not include storage in mine waste [12]. Australia is one step further since new legislation appears to apply also to ground level storage in mine waste streams [13]. The legislation distinguishes between 100-year and 25-year permanence projects. In the present study, the projected value of these carbon credits is assumed to be 100 USD/t CO₂.

Common to the EU and Australian regulations are some strict criteria for carbon storage certification. In the EU, these criteria are known as the “QU.A.L.ITY” criteria [14]:

1. QU: QUantification
Carbon removal activities need to deliver unambiguous benefits for the climate and be measured, monitored and reported accurately. Note that monitoring means monitoring for leakage and that this also needs to continue for a long time after storage closure.
2. A: Additionality
Carbon removal activities need to go beyond existing practices and what is required by law. Note that this implies that any naturally occurring carbonation is excluded and needs be deducted from actively achieved carbonation.
3. L: Long-term Storage
Certificates are linked to the duration of carbon storage and should ensure long-term storage.
4. ITY: SustainabiITY
Carbon removal activities must contribute to sustainability objectives such as climate change adaption, circular economy, water and marine resources and biodiversity.

These criteria imply that certification requires ongoing monitoring and registration of the quantities of CO₂ being mineralised and being maintained in storage. This requires periodic borehole sampling and analysis of the residue deposit area for establishing a baseline and for quantifying any losses over time.

make more sense to carbonate the waste lime streams that contain TCA rather than the entire bauxite residue stream to which these lime streams are added. Even better is to reduce the formation of TCA in the Bayer process all together since this will reduce the plant lime consumption and therewith the CO₂ emissions of burning CaCO₃ in lime kilns (chemically bound CO₂ as well as fuel combustion CO₂).

From a process technical perspective as well as an economic perspective it appears best to design an alkaline waste CO₂ mineral sequestration unit for the lowest practical pressure and lowest practical (e.g. with respect to agitation) L/S ratio. Dilution should always be avoided.

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