

The International Aluminium Institute's Bauxite and Alumina Committee: A Blueprint for Industry Collaboration

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Abstract

The Bauxite and Alumina Committee (BAC) is one of the five industry committees established by the International Aluminium Institute (IAI) to foster collaboration among member companies on shared challenges. Their mission is to drive projects that are aligned with the IAI board's strategic priorities and to be an industry reference group on the key issues and challenges. The BAC is a group of approximately 20 participants from member companies who are experienced technical specialists in the field of Bauxite, the Bayer process and Bauxite Residue (BR), and have a broad view of the industry. Over the past decade, the BAC's focus areas have been bauxite mining and BR management and reuse, safe transport of bauxite and BR by sea, remediation strategies for closed BR storage areas, proposals for safer storage of BR, and reuse in cement. Several reference documents and scientific publications were produced by the IAI as an output from these collaborative projects, which were completed in universities, research institutes and member companies' facilities. In many instances, the BAC has been the catalyst to these projects and ensured alignment with key industry priorities. The most recent and significant project is ReActiv, which is funded by the European Commission and aims at the development of processing routes to make Supplementary Cementitious Materials (SCM) from BR. This flagship project was a direct spin-off of BAC initiatives and exemplifies the alignment, integration and collaboration between an end-user (Holcim), the alumina industry, academia and research institutes. This article will highlight key BAC activities from the past decade and discuss the main factors that contributed to the success of industry collaboration.

Keywords: Bauxite, Processed bauxite (bauxite residue), Cement, Mining, Rehabilitation.

1. Introduction to the Bauxite and Alumina Committee (BAC)

The International Aluminium Institute (IAI) was established in 1972 as the International Primary Aluminium Institute, with the purpose of representing the global primary aluminium industry. The IAI has 25 signatory member companies, representing about half of global primary aluminium production with a broad geographical spread.

Initially, the principal function of the IAI was collecting and publishing production statistics. Over time, as the industry's complexity increased and stakeholder expectations evolved, the IAI expanded its role to encompass leadership in sustainability reporting, coordination of internal industry initiatives and the development of sector-specific standards and tools. Given that bauxite residue (BR) accounts for more than 90 % of the solid waste generated during the production of primary aluminium, the IAI established the Bauxite and Alumina Task Group (BATG) in 2004

to address associated challenges. In 2005, the BATG was reconstituted as the Bauxite and Alumina Committee (BAC).

The BAC is one of several IAI advisory committees, alongside Climate Change, Communication and Promotion, Environment and Nature, and Health Committees. It aims to support continuous improvement in BR management, specifically to mitigate the safety risks associated with storage in impoundments and to reduce the volumes through improved processing and the development of reuse strategies. As circular economy principles gain broader acceptance, the development of BR reuse applications have become an area of significant focus. The BAC convenes twice per year to review strategy and projects, while focussed working groups meet more regularly to review specific projects and themes.

The focus of BAC activities is often more technical than the other IAI committees, which is reflected in the makeup of its member participants. Member companies will typically appoint senior technical experts to represent them on the BAC and to take part in the various projects. The bi-annual BAC meetings typically host around 20 participants from over 10 companies and industry associations, creating a diverse group. A dozen countries are typically represented, and most participants do not have English as their first language. The BAC and the members of its working groups have more than 800 years of combined experience in our industry. The diversity is also reflected in the range of academic backgrounds and industry experiences: from chemists and chemical engineers to soil scientists, geologists and extractive metallurgists; having worked in R&D and technology development, refinery operation, university laboratories or mine site rehabilitation.

2. Impactful Achievements

Each year, a suite of projects aligned with the IAI strategic priorities are proposed by BAC members for review and selection by the IAI Board for funding. These projects have resulted in the delivery of significant and impactful achievements, which has been underpinned by the participation of industry experts and external consultants. A summary of these achievements is covered in this section.

2.1 Best Practice Storage and Management of Bauxite Residue

The 2010 alumina refinery tailings dam failure in Ajka, Hungary, prompted the BAC to enhance its review of safe BR storage and management practices, increasing focus on utilisation and remediation. Immediately after the incident, the BAC established a task force to provide advice and support to the Hungarian authorities. The IAI recognised the significance of the incident and published a voluntary code for the industry with five objectives: assured integrity of current residue storage facilities; the provision of industry-based support; best practice management; the end of BR solids disposal to marine and aquatic environment; and improved technology.

In subsequent years, a review of best management practices was performed, covering the storage and management, remediation of storage areas, and uses [1]. The review was later expanded to include more detailed data on BR storage practices, risk assessments, characteristics, work being undertaken for reuse opportunities and case studies. In 2015, the “Bauxite Residue Management: Best Practice” document was published in Chinese, Bahasa and English [2], and has since been updated and published in 2022 as “Sustainable Bauxite Residue Management Guidance” [3]. It remains a comprehensive guidance document for the industry and its stakeholders. It can be downloaded from the IAI website.

The increased focus on BR management, storage, remediation and reuse led to new IAI-funded initiatives in the fields of *in situ* remediation, leachate control using constructive wetlands,

assessment of metal uptake by plants, utilisation in cement, leaching methods and characteristics, transportation challenges and improved characterisation methodologies. The European Union (EU) also recognised the need to support increased utilisation of BR and significant funds were made available for this work. The IAI played a significant role in the establishment and subsequent participation in three EU-funded projects under HORIZON 2020. Namely, EU ETN-MSCA REDMUD Project (2014–2019) [4], RemovAL (2018–2023) [5], and ReActiv (2020–2025) [6].

2.2 Utilisation of Bauxite Residue in Cement

The use of BR as a component in cement manufacture was patented as far back as the 1930s but utilisation has been intermittent and until very recently, the usage rates were low. In 2013, the IAI launched a project to investigate the potential for utilisation of BR in cements and avenues to maximising its use. Three reports were prepared and published in 2016: “Opportunities for use of Bauxite Residue in Portland Cement Clinker” [7]; “Opportunities for use of Bauxite Residue in Supplementary Cementitious Materials” [8]; and “Opportunities for use of Bauxite Residue in Special Cements” [9].

The initial reports outlined the usage of unmodified BR as a raw meal feed material for Portland Cement Clinker production and specified the limitations. Although it was successful at low addition levels, up to approximately 3.5 %, its overall use was restricted to certain regions due to the availability of other raw materials. Much laboratory work had been undertaken to produce Supplementary Cementitious Materials (SCM), where addition levels of at least 30 % were anticipated, but at the time there was no industrial usage. Speciality cements had also been created using BR, but again, there was no industrial production.

Following the publication of these reports, discussions were held with various cement producers and associations. Additional efforts were made to address usage limitations and to develop a roadmap for overcoming these issues. This roadmap, titled “Technology Roadmap: Maximising the use of Bauxite Residue in Cement” [10], was published in 2020. At the same time, an Excel-based tool to quantify the benefits of using BR in cement, developed by the Ecole de Technologie Supérieure (Montréal, Canada), was published [11]. Since that time, the use of BR as a raw material for Portland Cement Clinker production has grown to almost 3 Mt per year.

To advance the utilisation of BR in SCMs, the BAC played a pivotal role in assembling a consortium of stakeholders, which initiated the ReActiv project. This project received an 8.8 million Euro grant from the European Commission. The ReActiv project comprised 23 partners, including one cement company, seven alumina producers, six universities, one research institute, as well as other specialised organisations. The objective of the project was to produce cements with a 30 % replacement of the clinker by modifying BR. Full implementation of the project would see the full utilisation of BR produced in Europe for cementitious products.

The project was perceived as a win-win for both the alumina and cement industries, reducing waste and CO₂ emissions, respectively. The focus was on transforming BR into a reactive material with pozzolanic or hydraulic activity suitable for new, low CO₂ footprint cement products. The project ended in April 2025, successfully producing several new SCMs on a small industrial scale: CB (co-calcined BR with kaolinitic clay at 800 °C), VB (iron-rich vitrified BR), and SB (iron-free smelted BR). A submission to SuStaCEM [12] has been made to have these products included in the European CEN TC51 standard as new SCMs for use in cement. The cement industry has encouraged the use of the term “processed bauxite” when discussing the use of BR in cement and this has now been adopted in submission to CEN TC51 and all ReActiv documentation [13]. The BAC has recommended that the entire alumina industry adopt the term “processed bauxite” for consistency and uniformity.

2.3 Leaching of Bauxite Residue

Some cement companies, dock owners, shippers and other stakeholders expressed concerns about the environmental impact of some species that could leach from BR. Consequently, in 2022, the IAI funded a work programme to assess the leaching characteristics of BR in outside storage prior to being used. Included in this study was a preliminary assessment of the leaching characteristics of cementitious products using clinker made with BR and modified BR, and the leaching characteristics of BR used in other applications that could result in leaching, such as road base.

Whilst laboratory leaching test data cannot directly replicate field leaching conditions, they help assess material leaching behaviour and identify species of potential concern. Various methodologies, originating from both the EU and US, were used for a wide range of BR samples from various locations. The percolation test used was EN 14405: 2017, a European Standard used to determine the leaching behaviour of inorganic and non-volatile organic substances from granular waste. Equilibrium test methodologies included EN 12457, TCLP (US EPA 1311) and SPLP (US EPA 1312).

The data from these tests have been used to compare against various international standards, including the EU waste classification criteria, and discharges to the freshwater aquatic environments in different countries.

2.4 The Transportation Challenge

As most alumina refineries are located near ports, transportation of BR by sea is crucial for developing new reuse markets. BR is typically produced using press filtration, dry stacking or mud farming, resulting in a 20–30 % moisture content. Liquefaction due to particle size, inter-particle forces, and moisture content poses a risk during sea transport in bulk cargo. This phenomenon increases bulkhead pressure with the likelihood of capsizing the vessel.

The Transportable Moisture Limit (TML) is the maximum moisture level in a bulk cargo that is considered safe for the material to be transported by sea. If the material has a moisture content greater than its measured TML, then liquefaction of the bulk cargo can occur. The TML must be determined accurately by an approved laboratory using the prescribed methods as stated in the IMSBC Code, using various test methods: Flow Table Test, Penetration Test and Proctor-Fagerberg Test.

A study commissioned by the IAI has shown the Proctor-Fagerberg test to be the preferred TML method for moist BR. The Proctor-Fagerberg test method is based on soil mechanics; it does not rely on visual interpretation by an operator and is generally considered the most reproducible method. The study demonstrated that the TML for several BR samples is close to typical values measured for press-filtered materials. Specific studies have since been undertaken using pelletisation and the adoption of additives to mitigate the risk of liquefaction.

2.5 Use of Constructed Wetlands to Treat Alkaline Runoff from BR Storage Sites

Following successful small-scale trials at a residue disposal site at Burntisland (UK) and work undertaken on other alkaline leachates, the IAI funded a project at the University of Limerick to trial the use of constructed wetlands to treat the alkaline run off from the BR storage site at Aughinish Alumina (Ireland). A horizontal surface flow constructed wetland (44 m²) was established using a mixture of locally sourced soils 20 cm in depth and planted with *Phragmites australis*. Input and output pH, EC and various chemical parameters were monitored monthly,

and plant performance was assessed by determining elemental content seasonally in aerial portions of *Phragmites australis* to assess the effectiveness of the approach [14, 15].

Over a five-year period, the wetland was effective in reducing the pH of the alkaline leachate to below licence requirements (< pH 9), and the elemental composition of the water met local EPA standards. Plant analysis displayed variable uptake of elements, but concentrations were below reported deleterious levels for leaf tissue [16].

2.6 *In Situ* Remediation of BR Storage Sites

A reliable, cheap and effective remediation strategy for BR storage areas is of considerable importance to the alumina industry, especially if it can be achieved without the use of topsoil. While topsoil-free routes using gypsum and manure had proved possible in certain climates, in 2012, the IAI embarked on a multi-year project to look at strategies for improving the success rate of remediation. The work encompassed several universities, McMaster University, University of Queensland and University of Western Australia and continued for 14 years in various phases. The initial programme involved assessing various remediated sites across the world for all the parameters that might be important. Stage 1 of the *In Situ* Remediation project concluded that the most promising approach to remediation would be bioremediation, applying principles that have been developed for the reclamation of saline-sodic soils.

Stage 2 aimed to investigate how BR responds to applied amendments and measure the effect of natural processes on modifying the BR towards a soil with targeted properties. This included evaluating the influence of factors such as climate, initial BR properties, choice of vegetation, topography and time. The objective was to identify opportunities to accelerate natural processes and highlight strategies for improving *in situ* remediation of BR that merit further evaluation. Four different field sites were investigated as part of the study. Results showed that the combination of chemical and physical amendments enhanced the effects of physical treatments in lowering salinity and pH, and coarsening soil texture. Addition of chemical and physical treatments decreased the dominance of haloalkaliphilic and halo-alkali-tolerant bacterial species within communities. Convergence in salinity and exchangeable Na⁺ and Ca²⁺ values over time between unremediated and remediated BR suggests that the remediation strategies that were used accelerated natural processes of *in situ* remediation and soil development. However, depletion of plant nutrients over time indicated that this ecosystem had not yet reached a stable state in which nutrient cycling processes were balanced and suggested that fertilisation and monitoring were required until nutrient availability has stabilised [17–24].

Stage 3 started in 2016 and examined the implementation of effective strategies identified in earlier stages of the work at a field scale. Lysimeters (10 × 20 m lined plots with drainage capture) were constructed at Alcoa's Kwinana refinery (Western Australia) to investigate geochemical, physical, and microbiological aspects of remediation and soil formation, as well as leachate chemistry. The programme investigated the interactions between chemical, physical and biological drivers of remediation during initial stages of soil development and evaluated the effectiveness of microbial and abiotic amendments for accelerating remediation. Other important aspects were the identification of mineralogical hosts for trace elements in BR, and how the oxidation state and fractionation of trace elements across phases may change during remediation [25, 26].

In 2018, the University of Limerick undertook a related project to assess metal uptake by various plants on two BR sites which had been remediated. To assess the ecotoxicological risk, plant bioassays (Phytotoxkit™ and the RHIZOtest) were performed on the vegetation and Al, As, Cr, V uptake was assessed [27]. A second part of the work examined the impact of BR treatments on earthworm (*Eisenia fetida*) survival [28].

2.7 The Alumina Technology Roadmap

Originally published in 2001, the BAC, in collaboration with the IAI's Alumina Technical Panel, played a crucial role in facilitating the updates of the Alumina Technology Roadmap [29]. The roadmap outlined a 15–20-year industry-collective vision for the global alumina sector to guide technological development, improve environmental and economic performance and strengthen sustainability. It addressed eight focus areas, including: raw materials, energy, BR, emissions, safety, the Bayer process, refinery construction and integrity, and Bayer process alternatives. Since the 2010 update, the roadmap has been instrumental in shaping the alumina industry's trajectory. The roadmap's influence is evident in several developments, namely: BR reuse, BR management and energy efficiency improvements that include decarbonisation technology.

2.8 Current and Future BAC Projects

Although much of the BAC's focus is on BR, the committee also works on sustainable bauxite mining and decarbonisation developments in alumina refining. For BR, there are currently three active projects: (i) ISO Standards: Unifying BR Characterisation, (ii) Pelletisation of BR, (iii) Mineral Carbonation of BR [30]. Future proposed projects, dependent on funding, include i) the integration of the Global Industry Standard for Tailings Management (GISTM) regulations into the published "Sustainable Bauxite Residue Management Guidelines", ii) a mapping exercise of all global chemical regulations, such as REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) [31] to construct a member guide on how to register BR, and iii) an update of the "Technology Roadmap: Maximising the use of Bauxite Residue in Cement" to include the latest developments from the ReActiv project and industry-wide developments since publication in November 2020.

2.8.1 Developing ISO Standard Methods

The multi-year project seeks to standardise the best-in-class laboratory procedures to accurately characterise the physical, elemental and mineralogical composition of BR.

Work undertaken during the recent EU-funded ReActiv project highlighted deficiencies in several of the commonly used test methods for characterising BR. Meanwhile, the alumina industry is also being asked to provide BR compositional data to potential end users. To address this, the BAC, in collaboration with industry members that are also representatives on ISO committees from various countries (e.g. Australia, Brazil), will seek to extend the remit of the "Aluminium ores" ISO committee (TC 79/SC 12) [32] to include BR, or pursue further routes for ISO accreditation of selected test procedures. Where this is not possible, the BAC will seek industry wide agreement on best-in-class standard test procedures for BR characterisation.

2.8.2 Pelletisation of BR

A study by the IAI highlighted that BR, even when processed with press filtration, is at or above the TML of the IMSBC Code (International Maritime Organisation). Under these circumstances, BR could be susceptible to liquefaction and hence a hazard for bulk shipment.

This project aims to demonstrate how pelletisation of BR, or the use of additives, could mitigate moisture levels to enable transport by sea, while making material handling easier when loading into ships and reusing within various industry applications. The study will help address whether it is possible, and cost effective, to ship BR – a necessary question that needs to be addressed to access potential markets.

2.8.3 Mineral Carbonation of BR

This project aimed to determine if a business case exists for pursuing active or passive carbonation of BR to assist with industry decarbonisation. It exemplified how member companies successfully combined their expertise to achieve consensus on a technical matter that has been the object of many research projects over the years [30].

The study concluded that there is no clear business case for pursuing either active or passive carbonation. Active carbonation is not economically viable due to several factors: the high capital cost, high operating cost, and the Scope 2 and 3 emissions approach the quantity of CO₂ sequestered. Passive carbonation offers no material economic benefits because the amount of CO₂ sequestered is too small and the rate is too slow to justify the costs associated with meeting the proofing, measuring and monitoring requirements for carbon credit certification. In addition, current legislation does not permit certification on the grounds that the additionality criterion is not satisfied.

3. Challenges, Now and in the Future

3.1 Public Perception of the Mining Industry

A fact often overlooked is that for every tonne of primary aluminium produced, approximately 4–5 tonnes of bauxite is mined and refined, which translates to more than 350 million tonnes of ore extracted each year. Mines are often situated in remote locations, irrespective, reducing their environmental impacts remains a focus for the industry. Mining activities impact natural habitats and produce tailings, underscoring the need to acknowledge and encourage responsible practices within the industry. The BAC provides a platform for exchanging best practices, which can be instrumental in addressing these challenges in the coming years.

The IAI hosts a public guide titled Sustainable Bauxite Mining Guidelines (Second Edition 2022) [33] to provide a practical and attainable approach to continuously improve mining operation sustainability. It includes theory and practical examples from collective experience over the past 50 years in the mining sector. This guide will be supported by a bilingual web-based infographic that is being developed to detail what best practice for mining bauxite means, from project concept to mine closure.

3.2 Carbon Footprint of an Alumina Refinery

The carbon footprint of the aluminium industry is mostly split between the use of electricity in the aluminium smelting process, the Scope 1 process emissions and the use of alumina. Converting the Scope 3 emission intensity into the GHG contribution, the alumina contribution can be up to 35 % of the GHG intensity of primary aluminium production. While refining alumina is less energy-intensive, it still requires an average of 10 GJ per tonne of alumina [34]. Approximately one third of this energy is, at present, thermal-based due to the alumina calcination process. The balance of the energy, in the form of steam required for the Bayer process, is mostly generated by burning fossil fuels, since very few plants operate electric boilers or biomass.

Using electric elements, plasma, or burning hydrogen to calcine aluminium hydroxide into alumina is technically challenging and strong industry collaboration is seen as an enabler to reduce CO₂ emissions. Consequently, the IAI has partnered with Australia's HILT-CRC [35] consortium, while at the same time bringing together the wider industry to facilitate knowledge sharing and accelerate technology development

3.3 Bauxite Residue: Image, Impact and Solutions

The quantity of BR generated for each tonne of alumina produced is variable, ranging from 0.6 to 4 tonnes of BR, depending on the bauxite ore used and processing conditions, with the average being between 1.2 and 1.3 tonne. Annually, this accounts for 93 % of all waste generated during the production of primary aluminium. Legacy BR, stored in impoundments, is estimated to be approximately 5 Gt, and with current forecast alumina production growth, stored volumes could grow to 10 Gt by 2050, reinforcing the importance of developing viable high-volume BR reduction, reuse, treatment and safe storage options.

BR is often viewed negatively from an environmental perspective due to its high alkalinity (pH 10–13) and the presence of heavy metals, in addition to its substantial volume and often distinct red colouration. If not stored properly, it can lead to soil and water contamination that may affect ecosystems. Public concern was significantly shaped over time by various incidents, the large physical footprint of BR impoundments and the challenges associated with rehabilitation.

To mitigate environmental risks, the aluminium industry stores BR in dedicated impoundment facilities. Advancements in pre-treatment methods have reduced the sodium and moisture content of BR, and hence the risk of groundwater contamination, with best-in-class press filtration now favoured over traditional disposal methods.

The importance of establishing best practices in the treatment and safe storage of BR is a priority of the IAI. This led the BAC to publish the first edition of the Sustainable Bauxite Residue Management Guidance in 2015, with a later update in 2022 [2, 3]. The BAC will continue to focus on new techniques to treat BR and its safe storage through alignment with GISTM. The reduction and reuse of BR remains a priority, with numerous guides and tools already published, as well as successive projects that have improved our understanding and supported the incremental uptake in reuse applications.

3.4 The Importance of Technical Knowledge and Experience

Despite its long history, the Bayer process is complex and constantly evolving and requires a skilled workforce to ensure it operates efficiently and produces high-quality alumina at a reasonable cost with minimal environmental impacts. Managing an array of challenges, such as variable bauxite quality or aluminium hydroxide precipitation size control underscores the need for skilled technical personnel in alumina refining. The industry will need to sustain a high level of technical expertise, particularly in a context where a significant proportion of experienced professionals approach retirement. Although modern tools and artificial intelligence will assist, they will not be sufficient on their own.

In 2025, the IAI launched the first-ever free online training course on aluminium [36], and ICSOBA offers short courses in electrolytic reduction and bauxite and alumina. While these are positive steps, our technical community is seeking to develop strategies to attract and retain talent necessary for long-term technical success.

4. Conclusions

The International Aluminium Institute (IAI) and its Bauxite and Alumina Committee (BAC) have played a pivotal role in advancing industry best practices related to bauxite, the Bayer process, and BR. Their efforts have fostered collaboration and innovation among IAI member companies, driving projects aligned with strategic priorities and addressing key industry challenges. The BAC's initiatives, such as the ReActiv project, have exemplified the alignment, integration, and collaboration between alumina companies, the cement industry, academia and research institutes.

The alumina industry has demonstrated that progress can be achieved through collaboration on common issues and challenges. This collaborative spirit is essential for the industry's future prosperity, as it enables the sharing of knowledge, resources and expertise to tackle complex problems to drive sustainable development. The BAC's success in fostering industry-wide cooperation highlights the importance of continued collaboration to address the evolving needs of the alumina sector and ensure its long-term growth and sustainability.

Through collaboration the BAC has initiated and supported several achievements, including:

- Publication of “Sustainable Bauxite Mining Guidelines” which focusses on the aluminium industry’s drive to ensure that bauxite mining is sustainable and minimises social and environmental impacts during operation and post-closure.
- Publication of “Bauxite Residue management: Best Practice” which followed the Ajka dam failure in Hungary, after which the BAC developed a voluntary code for industry practices to ensure safe storage and management of bauxite residue.
- Ongoing reviews on the utilisation of BR, especially in cement, which resulted in several publications including a “Roadmap to maximise the opportunities for bauxite residue in cementitious materials.” This was a key document that increased interest in the topic resulting in the EU funded ReActiv project aimed at producing new SCMs.
- Remediation strategies for BR disposal areas: various initiatives have been launched to investigate effective remediation methods for closed storage sites, including bioremediation techniques and the use of constructed wetlands. Other projects discussed include refinery decarbonation, an assessment of the mineral carbonation of BR, the pelletisation of BR for safe transport by sea and more in-depth characterisation of BR including leaching and standardisation of analyses.

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