This article provides a background on sustainability in the mining and minerals industry, including Bauxite & Alumina (Bx & Aa), and explores relationships between sustainability and quality criteria for Bx deposits, respectively design criteria for Aa refineries.

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Sustainability aspects of bauxite deposits and alumina refineries

Sustainable Development: "People, Planet, Profit, Governance"
The Global Mining Initiative (GMI) led by companies making up the mining and minerals working group of the World Business Council for Sustainable Development (WBCSD) commissioned the independent Mining, Minerals and Sustainable Development (MMSD) project, conducted by the International Institute for Environment and Development (IIED).

In the Executive Summary of the 2002 MMSD report it is stated: "One of the greatest challenges facing the world today is integrating economic activity with environmental integrity, social concerns, and effective governance systems. The goal of that integration can be seen as "sustainable development". In the context of the minerals sector, the goal should be to maximise the contribution to the well-being of the current generation in a way that ensures an equitable distribution of its costs and benefits, without reducing the potential for future generations to meet their own needs". In other words the four dimensions of Sustainable Development (SD) comprise:

- Social sphere often referred to as "People" aspect.
- Environment ("Planet").
- Economics ("Profit").
- Governance sphere providing the backdrop for the other three (the three "pillars" of SD).

This builds on the most widely accepted definition of SD by the 1987 Brundtland Commission on Environment and Development: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Fig 1).

The International Council on Mining and Metals (ICMM) developed the SD framework comprising three elements which member companies are required to implement: 1. Commitments: 10 principles for SD, based on the issues identified in the MMSD project; 2. Public reporting: Performance reporting against the 10 principles in accordance with the guidelines of the Global Reporting Initiative (GRI); and 3. Independent assurance: Providing third-party verification against five aspects that a company is meeting its commitments to the 10 principles.

Sustainability reporting guidelines
GRI’s Reporting Guidelines are the generally accepted framework for reporting on an organisation’s economic, environmental, and social performance, and are used by many Al industry majors as standard for sustainability reporting. ICMM members are committed to reporting against the Mining and Metals Sector Supplement (MMSS). The mining and metals sector includes exploration, mining and primary metal processing (refining, smelting, recycling and basic fabrication) and covers the complete project life cycle from development through operational lifetime to closure and post-closure. The Guidelines comprise (Fig 2):

Part 1 - Reporting Principles with three main elements: Defining Report Content; Reporting Principles for Defining Quality; and Reporting Guidance for Boundary Setting.

Part 2 - Standard Disclosures specifying base content that should appear in a sustainability report with disclosures on: Strategy and Profile; Management Approach; and Performance Indicators providing comparable information on the organisation’s economic, environmental, and social performance.
The sections on Management Approach and Performance Indicators are organised by the categories Social, Environmental, and Economic, with Disclosures covering the following aspects (Fig 3):

- **Social**: Labour Practices; Human Rights; Society; and Product Responsibility.
- **Environmental**: Materials; Energy; Water; Biodiversity; Emissions, effluents, and waste; Transport; Products and Services; and Compliance.
- **Economic**: Economic performance; Market presence; and Indirect economic impacts.

### SD Goals

The March 2013 joint UN Global Compact – WBCSD report included inputs by business leaders w.r.t. scope and nature of SD Goals. These should:

1. Reflect the 3 pillars of SD; 2. Include a dimension related to equitable economic growth; 3. Adequately address water, energy, food, and the effective management and maintenance of ecosystems services; and 4. Appropriate timeframe is 15 years, with five-year reviews involving all stakeholders.

The Responsible Aluminium Scoping Phase (RASP) was a response from a working group of industry-based organisations and non-profit stakeholders to a demand for products produced to the best social and ecological standards throughout the supply chain. Their report included a preliminary list of identified issues for the upstream part of Al through its entire value chain.

### Corporate strategic sustainability targets

The long term (LT)/strategic sustainability targets published by industry majors (Alcoa, Rusal, Rio Tinto, Hydro, BHP Billiton) are in broad terms in line with the SD goals discussed above:

- **Social**: 1. Zero fatalities; 2. Increase diversity (w.r.t. representation by women, minorities, locals in management, etc); 3A. Zero significant community incidents; 3B. Funds and activities targeted for community assistance programs and sometimes infrastructure (e.g. medical clinics).

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**Table 1** Bauxite deposit quality criteria & their sustainability facets

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<thead>
<tr>
<th>Bauxite deposit quality criterion</th>
<th>Target</th>
<th>Related GRI performance indicator</th>
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<tbody>
<tr>
<td>2. Distance resource - port</td>
<td>Rail (+ other): 150km max Bx slurry pumping: 100km min</td>
<td>Economic: EC1 Environmental: EN12-MM1, EN14 Social: SO1, SO1-MM9</td>
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<tr>
<td>3. Disturbed acreage per tA produced$^2$</td>
<td>0.35m$^2$/tA</td>
<td>Economic: EC1 Environmental: EN12-MM1, EN21, EN22-MM3 Social: SO1, SO1-MM9</td>
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<tr>
<td>4. Material handled per tA produced, split over</td>
<td>4A material mined$^3$</td>
<td>3.4 tA max (dry basis)$^3$ Economic: EC1 Environmental: EN1, EN21, EN22-MM3 Social: SO1, SO1-MM9</td>
</tr>
<tr>
<td>4B residue to disposal$^4$</td>
<td>1.2 tA max (dry basis)$^4$ Economic: EC1 Environmental: EN4, EN12-MM1, EN21, EN22-MM3 Social: SO1, SO1-MM9</td>
<td></td>
</tr>
<tr>
<td>5. Alumina in bauxite</td>
<td>2% max</td>
<td>Economic: EN3, EN16, EN20 Environmental: EN1 Social: EN14</td>
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<tr>
<td>6. Total caustic consumption per tA produced$^5$</td>
<td>75kgtA max (100% NaOH basis)</td>
<td>Economic: EN3, EN21, EN22-MM3 Environmental: EN3, EN21, EN22-MM3 Social: SO1, SO1-MM9</td>
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<tr>
<td>7. Ratio % extractable organic carbon/% available Al$^6$</td>
<td>0.002 max $^6$</td>
<td>Economic: EC1 Environmental: EN4, EN12-MM1, EN21, EN22-MM3 Social: SO1, SO1-MM9</td>
</tr>
<tr>
<td>8. Resource contained alumina</td>
<td>30 years$^7$</td>
<td>Economic: EC1 Environmental: EN4, EN12-MM1, EN21, EN22-MM3 Social: SO1, SO1-MM9</td>
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1. Capex for railway, housing, roads, resettlement, and non-refinery related port items (eg jetty, power supply). 2. At in-situ bauxite SG=1.85 and mining recovery=90%. 3. Includes overburden and bauxite beneficiation tailings (if applicable), at mining recovery=90%. 4. Bauxite residue to disposal, incl sand and lime products. 5. Incl chemical soda loss (reactive SiO$^2$), physical soda losses (bauxite residue), and other losses (eg oxalate, product, etc). 6. Assuming an extraction efficiency of about 50%, this means effectively a ratio of %TOC/%avail. Aa of ~0.004 (TOC= total organic carbon). 7. E.g. for a 1MtAl alumina refinery project: 30Mt contained alumina, or in situ bauxite about 30x3=90Mt. 8. First quartile/median of global bauxite mines excl China.
Environmental: 1. Reduce Greenhouse GHG or CO₂ emissions; carbon based energy consumption/tA; and fresh water consumption/tA; 2. Improve ratio of new mining disturbance to rehabilitation/forestation; 3. Alcoa specifies targets for rehab of Bx residue storage areas and recycle/reuse of Bx residue. Hydro has “ambitions to improve existing situation by implementing new dry disposal technology” and “continues to investigate options for Bx residue utilisation”; 4. Biodiversity: Not very specific targets.

Economic: Only some of the majors mention specific economic targets directly as element of their sustainability goals, however all of them refer in their annual report to the need to focus on reducing costs and improving productivity and several refer to specifics such as improving beneficiation and refinery processes, etc.

Impact of Bauxite deposit quality
Basic data normally provided on Bx deposits includes items such as Bx layer thickness, Overburden/Bx ratio, % Available Alumina, Reactive Silica, etc. Although these are important for a resource evaluation, they do not provide a comprehensive understanding of its strengths and weaknesses. This requires a review of deposit quality in its widest sense, including elements such as strengths and weaknesses w.r.t. energy, water, and materials consumption, and waste (overburden, tailings, etc), project capital and operating costs (capex and opex), and impact on communities, resettlements, etc.

Major resource quality aspects therefore are: Location (country, export port, relocation requirements); Logistics (accessibility of, and logistics to the port via which raw materials are imported and Aa/Bx exported); Accessibility of the deposit relative to the port (distance, river crossings, etc); Deposit characteristics (Overburden and Bx layer thickness, beneficiation requirement, etc); Refinery feed characteristics (% Available Alumina, Boehmite, Reactive Silica, Impurities, etc) – Bx mineralogy and chemical composition influence refinery process conditions and associated raw material consumption and capital requirements; and Resource size (a resource should be able to support a refinery project for its lifetime – typically 40+ years). Bauxite resource quality in this sense may affect about a third of refinery plant capex or about half of total project capex if mine and infrastructure capex are included, and has a more profound effect on opex than technology/design. The selected deposit quality criteria should therefore account for the above mentioned elements.

Deposit quality criteria
In summary, a set of Bx deposit quality criteria should be limited to major issues, provide target values, and importantly: Should not be applied rigidly. In other words a resource not meeting one (or perhaps more) target value(s) should not necessarily be excluded, but the overall result should be considered. “Strategic” criteria which could result in a different outcome of a resource review have not been included here (e.g. importance to be present in a country for other reasons than participating in a Bx and Aa project). Table 1 presents a set of quality criteria for Bx deposit review purposes addressing the above elements, and includes references to relevant GRI performance indicators, illustrating the relationship between these quality criteria and sustainability facets.

Conclusions
Table 1 illustrates that quality criteria for the evaluation of a Bx deposit span
economic, environmental and social aspects, the three pillars of SD. In other words sustainability in the context of Bx deposits is not abstract or isolated from “the real world”, but can be qualified and quantified. The table also shows that economic and environmental (in some cases social) aspects are mostly intertwined. Putting it differently, economically more attractive deposits are often also more attractive in environmental terms.

Several of the criteria of Table 1 are consistent with the issues for the upstream steps of the Al value chain from RASP (e.g. waste management, land use and social resettlement for Bx mining – refer section 0). And all of them are consistent with the LT/strategic corporate sustainability targets of industry majors (refer section 0), implying sustainability’s growing role. It appears therefore reasonable to assume that Bx deposit quality in its widest sense, including sustainability aspects, will play an ever more important role in future development decisions on greenfield Bx and Aa projects.

**Refinery design and sustainability**

The selection of a Bx deposit for an Aa refining project has a profound effect on the design of the refinery as discussed above, i.e. the choice of a specific Bx feed influences several important refinery design criteria. However other design criteria are chosen (partly) independent of Bx quality: Process conditions (e.g. plant liquor productivity/yield); Equipment technologies and layout (e.g. for digestion, Bx residue settling, overall plant); Plant location specifics affecting plant design (e.g. rainfall, country legal requirements w.r.t. emission standards); Operating and maintenance philosophies of project owners (e.g. with respect to outsourcing activities, integration of maintenance and operational activities, etc).

**Design criteria**

It is not possible to cover all refinery design criteria in the context of this article. However some of the main ones and their sustainability facets are included in Table 2 with references to relevant GRI performance indicators, illustrating the relationship between these criteria and sustainability.

**Conclusions**

As with the Bx deposit quality criteria, the emerging perspective is that key design criteria of an Aa refinery include the three pillars of SD. Once Bx characterisation test work has been completed and project size decided, sustainability in the context of refinery design can be qualified and quantified. Table 2 also shows that economic and environmental aspects are most of the time two sides of the same coin, while social aspects are often also integral to refinery design. Put differently optimum refinery design in economic terms is (LT) often also the most attractive environmentally (and sometimes socially).

Most of the criteria of Table 2 are consistent with the issues for the upstream steps of the Al value chain from RASP (e.g. Bx residue management; SO₂, CO₂, and NOₓ emissions; energy efficiency; and caustic soda management for Aa refining. And most are consistent with the LT/strategic company targets of industry majors. The trend seems that sustainability will play a more prominent role in future decisions on the design of brownfield and greenfield Aa refinery projects. Elements of that trend include: a continuing push to increase plant liquor yield (Table 2, item 1); finding new approaches and technologies to improve plant and process efficiencies (a.o. item 10) including a growing thrust to improve on Bx residue disposal (item 9); and developing a more sustainable energy supply (item 7).