Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

SUSTAINABILITY AND BAUXITE DEPOSITS

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Keywords: Sustainability, Bauxite, Deposit, Deposit Quality, Alumina

1. Abstract

Sustainability plays a growing role in the development of (future) projects in the mining and minerals industry, including the Bauxite and Alumina industry. The relationship between sustainability criteria and structures, and their applicability to our industry is not always clear. In addition it may appear sometimes that the implementation of sustainability criteria for new projects affects project economics negatively.

This paper provides a background on sustainability in the mining and minerals industry, and explores the relationships between sustainability and quality criteria for bauxite deposits.

2. Sustainability in Mining & Minerals

2.1 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 – incl. Alcoa, Rio Tinto, BHP Billiton, Vale, Hydro, and Vedanta Resources) commissioned the independent Mining, Minerals and Sustainable Development (MMSD) project [1]. This project was conducted by the International Institute for Environment and Development (IIED) between 2000 and 2002. In the Executive Summary of the 2002 MMSD report "Breaking New Ground" it is stated [2] that "*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 maximize 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*". This builds on the most widely accepted definition of sustainable development by the World Commission on Environment and Development (1987 Brundtland Commission): "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*[1]". The four dimensions of sustainable development thus identified are [2]:

- **Social** sphere sometimes referred to as the "People" aspect.
- **Environmental** sphere ("Planet" aspect).
- **Economic** sphere ("Profit" aspect).
- **Governance** sphere providing the setting for the other three aspects (the three "pillars" of sustainable development).

In summary sustainable development involves integrating and meeting economic, social, and environmental goals [2]. In their 2012 report MMSD+10 ("Reflecting on a decade of mining and sustainable development"), the IIED mentions that "*MMSD helped companies understand that sustainable development is about balancing the needs of society, the environment and economics, in the context of good governance*" [3]. The Australian Minerals Industry's Framework for Sustainable Development ("Enduring Value") defines Sustainable Development in the mining and metals sector to mean that "*investments in minerals projects should be financially profitable, technically appropriate, environmentally sound and socially responsible*".

Prompted by GMI the board of the metals industry's representative organization, the International Council on Metals and the Environment agreed in 2001 to broaden its mandate and transform itself into the International Council on Mining and Metals (ICMM). Currently ICMM members include 22 mining and metals companies (e.g. Hydro, Rio Tinto, BHP Billiton, and Vale) and 34 national and regional mining associations and global commodity associations (e.g. International Aluminium Institute, and the Minerals Council of Australia). ICMM developed the Sustainable Development Framework consisting of the following three elements which member companies are required to implement (refer website www.icmm.com):

- **Commitments**: 10 principles for sustainable development based on the issues identified in the MMSD project and benchmarked against several leading international standards.
- **Public reporting**: performance reporting against the 10 principles in accordance with the guidelines of the Global reporting initiative (GRI) (refer section 2.2).
- **Independent Assurance**: providing third-party verification against 5 aspects that a company is meeting its commitments to the 10 principles.

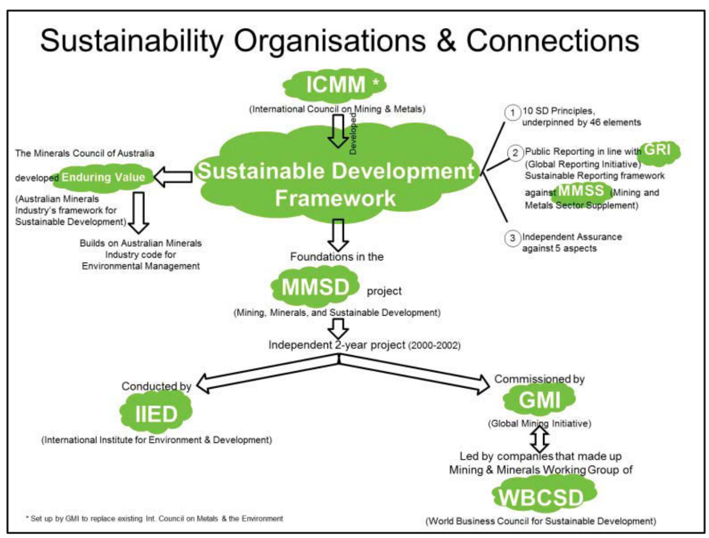

Figure 1 – Sustainability Organizations and Connections

Figure 1 shows the connections between the above mentioned councils, committees and sustainability related facets.

[1] World Commission on Environment and Development. Our Common Future. Oxford: Oxford University Press, 1987, p.43

2.2 Sustainability Reporting Guidelines – Mining & Metals Sector Supplement

The GRI Reporting Guidelines – now in their third generation (G3) – are intended to serve as a generally accepted framework for reporting on an organization's economic, environmental, and social performance [4]. They are used by many aluminium industry majors as standard for sustainability reporting although they are applicable to organizations of any size, type, sector or geographic region. ICMM members are committed to reporting against the Mining and Metals Sector Supplement (MMSS). The mining and metals sector in this context includes exploration, mining and primary metal processing (incl. refining, smelting, recycling and basic fabrication) and covers the project life cycle from development through operational lifetime to closure and post-closure. The Guidelines consist of Reporting Principles and Guidance, and Standard Disclosures (incl. Performance Indicators) broken down as follows:

1. **Part 1 Reporting Principles and Guidance** with three main elements of the reporting process:
    - Defining Report Content;
    - Reporting Principles for Defining Quality; and
    - Reporting Guidance for Boundary Setting.
2. **Part 2 Standard Disclosures** specifying the base content that should appear in a sustainability report with disclosures on the following topics:
    - **Strategy and Profile** setting the overall context for understanding organizational performance such as strategy, profile, and governance;
    - **Management Approach** covering how an organization addresses a given set of topics in order to provide context for understanding performance in a specific area;
    - **Performance Indicators** providing comparable information on the economic, environmental, and social performance of the organization.

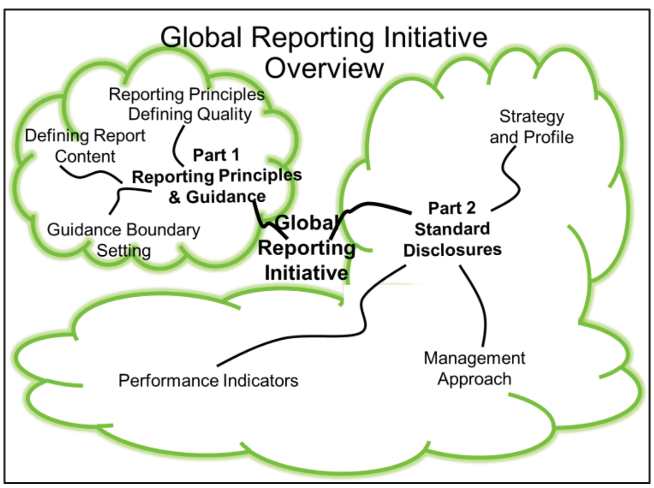

Figure 2 – Global Reporting Initiative - Overview

The sections on Management Approach and Performance Indicators are organized by the categories economic ("Profit"), environmental ("Planet"), and social ("People"). Many of the major companies in the Bauxite and Alumina industry such as Rio Tinto, UC Rusal, Alcoa, Norsk Hydro and BHP Billiton report on their sustainability performance applying GRI reporting guidelines. Figure 2 illustrates the above showing the main subjects for each of the report sections.

Disclosures on Management Approach and Performance Indicators cover the following aspects:

- **Social**: 1. Labor Practices; 2. Human Rights; 3. Society; and 4. Product Responsibility.
- **Environmental**: 1. Materials; 2. Energy; 3. Water; 4. Bio-diversity; 5. Emissions, effluents, and waste; 6. Transport; 7. Products and Services; 8. Compliance; and 9. Overall.
- **Economic**: 1. Economic performance; 2. Market presence; and 3. Indirect economic impacts.

Figure 3 shows the GRI Sustainability performance indicators broken down into major sub-indicators for a Bauxite Mine & Alumina project (refer [4] for more details).

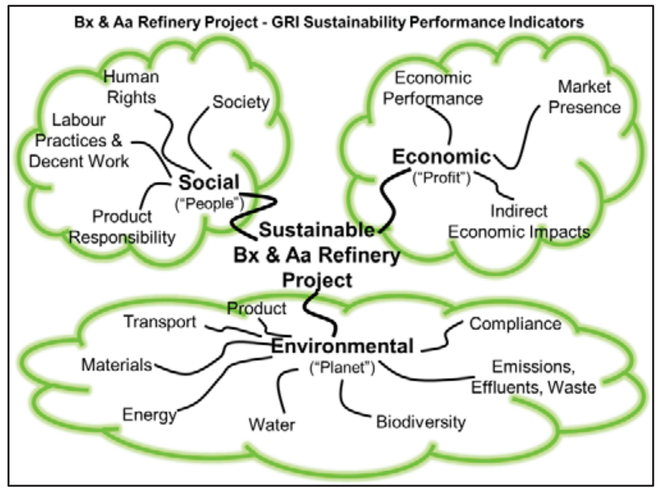

Figure 3 – Global Reporting Initiative – Performance Indicators

2.3 Sustainability Development Goals

The WBCSD presented in March 2010 their report on the 18-month project Vision 2050 in which 29 WBCSD member companies (incl. Alcoa and Rio Tinto) developed a vision of a world on the way to sustainability by 2050 [5], and a pathway leading to that goal, detailing nine elements: 1. People values; 2. Human development; 3. Economy; 4. Agriculture; 5. Forests; 6. Energy and power; 7. Buildings; 8. Mobility; and 9. Materials.

In the report "corporate sustainability" is described as meaning the delivery of long-term value in financial ("profit"), environmental ("planet"), social ("people"), and ethical ("good governance") terms.

In order to reach WBCSD's vision for 2050, actions are required on many fronts, the most critical changes occurring in terms of:

- **Carbon & Resources**: Halve the CO_2 emissions from 2005 levels; Double agricultural output by 2050; Increase resource and material efficiency 4-10 fold; halt deforestation.
- **Costs**: Incorporate costs of carbon, water and major ecosystem services.
- **Consumption**: Change consumption patterns to more sustainable lifestyles.

In March 2013 a joint UN Global Compact – WBCSD report to the high-level panel of the post-2015 UN Development Agenda was presented which included the following thoughts by business leaders in relation to the possible scope and nature of Sustainable Development Goals (SDG's) [6]:

- SDG's should reflect and balance the three pillars of sustainable development – economic, environmental, social – while also being global in applying to all nations.

- SDG's should include a clear dimension related to equitable economic growth, especially one emphasizing economic sustainability and inclusiveness. It was recognized that development objectives cannot be achieved without economic growth – but also that economic growth does not ensure sustainable development. Therefore, any SDG related to economic growth should strongly address employment, while also seeking to upgrade the quality of jobs. Negative externalities should be priced appropriately and included in measurements of economic growth and societal well-being.
- SDG's should adequately address the link of water/sanitation; energy; food/hunger; and the effective management and maintenance of biodiversity, ecosystems and ecosystems services through possible stand-alone goals in each area.
- An appropriate timeframe for SDG's is 15 years, with 5-year reviews involving all stakeholder groups.

The Responsible Aluminium Scoping Phase (RASP) was a response from a working group of industry-based organizations (incl. Alcoa, BHP Billiton, Norsk Hydro, and Rio Tinto Alcan) and a number of not-for-profit stakeholders (incl. the Int. Aluminium Institute and the Australian Al Council) to a demand for products with definite origins, produced to the best social and ecological standards throughout the supply chain. RASP was a 6-month project conducted by Track Record Global Ltd, administered by the Eden Project and in consultation with participating industry and not-for-profit stakeholders. Their report was issued in December 2010 [7], and includes the following preliminary list of identified issues for the upstream steps of the aluminium value chain (which includes but is not limited to bauxite mining and alumina refining [8]):

- **Bauxite Mining Issues**: 1. Waste Management; 2. Dust Emissions; 3. Noise Management.
- **Alumina Refining Issues**: 1. Bauxite Residue Management; 2. SO_2 Emissions; 3. NO_x Emissions; 4. Caustic Soda Management.
- **Aluminium Upstream Issues** (also relevant to Bauxite mining and Alumina Refining): 1. Land Use and Biodiversity; 2. Energy efficiency; 3. CO_2 Emissions; 4. Social Displacement and Resettlement;
- **Aluminium Value Chain Issues** (also relevant to Bauxite mining and Alumina Refining): 1. Transparency and Business Ethics; 2. Human Rights; 3. Labour Rights; 4. Water Management; 5. Health and Safety; 6. Transport and Corridor Management; 7. Sustainability of Communities.

Building on the work done, the Aluminium Stewardship Initiative (ASI, members include Rio Tinto Alcan and Norsk Hydro) was launched in 2012 to enhance sustainability and transparency throughout the Aluminium industry. ASI's main aim is to develop a global standard for aluminium sustainability by the end of 2014, to foster responsible resource management of aluminium through its entire value-chain.

2.4 Corporate Strategic Sustainability Targets

The (long term) strategic sustainability targets published by industry majors (Alcoa, Rusal, Rio Tinto, Hydro, BHP Billiton) are in broad terms in line with the sustainable development goals discussed in the previous section:

- **Social targets** mentioned are:
  - Zero fatalities or (serious) injuries.
  - Improving recordable injury rates.
  - Occupational illnesses: establishing baseline health exposure assessments, resp. reducing these illnesses.
  - Increasing diversity w.r.t. representation by women, minorities, and locals in management, graduate intake, etc.
  - Community: Zero significant community incidents, funds and activities targeted for community assistance programs and sometimes infrastructure (e.g. medical clinics), community engagement and organizations, support of health and safety programs (e.g. HIV, malaria), developing grievance mechanisms, etc. BHP Billiton targets to have 1% of pre-tax profits invested in community programs, including cash, in-kind support and administration. Rio Tinto specifies that all their operations should have in place by 2013 locally appropriate, publicly reported social performance indicators that demonstrate a positive contribution to the economic development of the communities and regions where they work, consistent with the Millennium Development Goals. Hydro targets to meet the UN Millennium Development Goals by 2015. Alcoa has been active for many years through their Alcoa Foundation.
- **Environmental targets** mentioned are:
  - Reducing greenhouse gas (GHG) or CO_2 emissions, (carbon based) energy consumption per tonne product, and fresh water consumption per tonne of product.
  - Improving the ratio of new mining disturbance to rehabilitation / reforestation. Hydro indicates to "have ambitions to develop improved beneficiation and refinery processes, which will enhance efficiency in the use of raw materials and allows utilizing a greater portion of the marginal bauxite ore, in this aiming to reduce the area affected per ton bauxite extracted".
  - Alcoa specifies targets for rehabilitation of bauxite residue storage areas and the recycle / reuse of residue. Norsk Hydro mentions to "have ambitions to improve the existing situation (dry stacking technology) by implementing new dry disposal technology" and to "also continue to investigate options for residue utilization".
  - Biodiversity: not very specific targets – developing plans, resp. protecting or enhancing biodiversity.
- **Economic**: although only some of the majors mention specific economic targets directly as element of their sustainability goals, all of them refer in their annual report to the need to focus on reducing costs and improving productivity, while several refer in this context to specifics such as lowering manning levels, improving beneficiation and refinery processes, etc.
- **Other**: many of the majors emphasize investing in R&D / innovations / developing new technology to minimize environmental impact and improve economics, etc.

In the above context the following chapter explores relationships between sustainability and quality criteria of bauxite deposits.

3. Bauxite Deposit Quality Criteria and Sustainability

3.1 Impact of Deposit Quality

Basic data normally provided on bauxite deposits include items such as bauxite horizon thickness, overburden / bauxite ratio, mineralogy, % Available Alumina, Reactive Silica, TOC, and impurities, etc. These are essential to perform a resource evaluation however they do not by themselves provide the information required for an overall understanding of the strengths and weaknesses of a bauxite resource.

Such an understanding requires a review of the quality of a bauxite resource in its widest sense – a key aspect of a Bauxite & Alumina project which has a significant bearing on the elements forming part of Sustainability ("Planet", "Profit", "People"): its environmental strengths and weaknesses (w.r.t. energy, water, and materials consumption, biodiversity, and waste – overburden, tailings, etc), its capital and operating costs (capex and opex), and its social strengths and weaknesses (impact on communities, resettlements, etc).

Major resource quality aspects are:

- **Location** (country, export port, relocation requirements): includes country aspects such as the presence and state of repair of a port (via which raw materials are imported and alumina is exported), of a rail road (if the deposit is a significant distance from the port), a town site (incl. hospital), roads, and water availability, and the requirement to relocate people living on the deposit. These aspects may be combined in "infrastructure" capex and opex. Other country aspects include royalties (on bauxite or alumina), levies, duty on raw materials, the effect of legislation (e.g. with respect to environmental requirements), taxes, and tax holidays.
- **Logistics**: accessibility of and logistics to the port via which raw materials are imported (e.g. caustic soda, coal, fuel oil, lime) and alumina / bauxite is exported. This element is influenced by port location, ship size (water depth – need to dredge) and the proximity to frequently used sea lanes, as reflected in the cost of raw materials CIF the importing port and/or in freight charges for the export of alumina / bauxite.
- **Accessibility** (distance, height, mountain, river crossings) of the deposit relative to the port, reflected in capex and opex related to transportation, either of the raw materials and alumina to the refinery site or of the bauxite to the (refinery at the) port.
- **Deposit characteristics** (uniform vs. pockets, overburden and bauxite horizon thickness, beneficiation requirement), affecting costs of mining, crushing, storage, beneficiation, rehabilitation, etc. This aspect is reflected in the overall \$/tBx cost CIF refinery (bauxite transportation may either be included – e.g. if the mine is close to the refinery, or be covered by a separate transportation cost) and in the related mine capex.
- **Refinery feed bauxite characteristics** (hardness, % Available alumina – level and % gibbsite/boehmite, reactive silica, impurities): bauxite mineralogy and chemical composition dictate several process conditions of the Bayer refining process and associated raw material consumption and capital requirements, i.e. the quality of the bauxite feeding an alumina refinery has a significant impact on process conditions and raw materials consumption. These aspects are mainly reflected in refinery capex and opex related to bauxite, caustic soda and energy consumption, and residue disposal.
- **Resource size**: a bauxite resource should be able to support a refinery project for its lifetime (typically 50^{+} years; however for evaluation purposes a 30 year lifetime is often used).

Bauxite resource quality in its widest sense may affect about a third of plant capex or about half of total project capex if mine and infrastructure capex are included [9], and has a more profound effect on opex than technology / design [10]. In other words it is important to review a bauxite resource's quality criteria taking account of the above elements.

3.2 Bauxite Deposit Quality Criteria

In general terms deposit quality criteria should focus on major issues, provide target values, and they should not be applied rigidly. In other words a resource not meeting one (or perhaps more) of the target values should not necessarily be excluded, but the overall result of a resource review should be considered. Strategic criteria which could result in a different outcome of a review have not been included (e.g. importance of a presence in a particular country for other reasons than participating in a bauxite and alumina project).

Table 1 presents a set of quality criteria used for bauxite deposit review purposes addressing the elements mentioned in section 3.1. The table includes references to relevant GRI performance indicators (refer [4]), illustrating the relationship between these quality criteria and their sustainability facets.

The rationale behind these criteria is as follows:

1. **Country infrastructure capex maximum 250 \$/Annual tA production capacity**: this criterion refers to several elements: physical systems (housing, railway, access roads, bridges, port facilities); a country's legal framework; and the requirement to resettle people on the deposit. It affects local employment and local communities. If the capex for country infrastructure increases well above this number (e.g. when a new port needs to be developed, and a large number of people require resettling) the negative effect on project economics may become unacceptable. Its effect on opex may range from low (e.g. limited royalty requirements and no physical infrastructure to run) to significant (bauxite levies and extensive infrastructure opex). Some aspects may be negotiable and therefore more difficult to quantify at an early stage of a project. In addition a country's government and/or other third parties may be interested to assume responsibility for (some of) the physical infrastructure requirements.
2. **Distance bauxite resource to alumina export port maximum 150 km**: if the transportation distance increases significantly above this number (worldwide range: indicatively 10-360 km), raw materials and alumina or bauxite transportation costs increase prohibitively. For bauxite slurry pumping, in which case the bauxite is pumped in slurry form from the mine site to the refinery located at the port, the opposite applies: this technology may become a viable alternative for distances above ~100 km. The impact of bauxite slurry pumping on the refining process such as bauxite de-watering, additional evaporation requirements etc must be taken into account in the design of the alumina plant. If appropriate design measures are taken, slurry pumping should have less environmental impact than the installation of a rail road.
3. **Disturbed acreage maximum 0.35 m^2/tA**: the strength of this criterion is that it is a function of a number of characteristics of the resource (bauxite horizon thickness, in-situ SG, % Available alumina and moisture); mining (mining recovery); and processing (beneficiation/washing recovery, refinery alumina recovery). Its global range is ~0.1-1.1 m^2/tA. It is proportional to the inverse of the effective bauxite horizon thickness, and it has an impact on the three sustainability aspects "Profit" (mining and rehabilitation opex, and beneficiation capex and opex if applicable), "Planet" (disturbed & rehabilitated land, and biodiversity),

Table 1 – Bauxite Deposit Quality Criteria & Their Sustainability Facets

Bauxite Deposit Quality Criterion	Target	Related GRI Performance Indicator		
		Economic	**Environmental**	**Social**
1. Country Infrastructure Capex①	250 US$/Ann tA max	EC1, EC4, EC8, EC9		LA1, SO1, SO1-MM9
2. Distance Resource – Port	Rail (+ other): 150 km max Bx slurry pumping: 100 km min	EC1	EN4, EN29	
3. Disturbed Acreage per tA produced②	0.35 m^2/tA max②⑧	EC1	EN12-MM1, EN14	SO1, (SO1-MM9)
4. Material Handled per tA , consisting of				
4A Material Mined③	3.4 t/tA max (dry basis) ③⑧	EC1	EN1, EN21, EN22-MM3	SO1, (SO1-MM9)
4B Residue to Disposal④	1.2 t/tA max (dry basis) ④⑧	EC1	EN4, EN12-MM1, EN21, EN22-MM3	
5. Alumina in Boehmite	2 % max	EC1	EN3, EN16, EN20	
6. Total Caustic Consumption per tA⑤	75 kg/tA max⑤⑧ (100% NaOH basis)	EC1	EN1, EN4	
7. Ratio Extractable Organic Carbon / Available Al_2O_3	0.002 max⑥⑧	EC1	EN3, EN21, EN22, EN22-MM3	
8. Resource Contained Alumina	30 years min⑦	EC1		SO1, (SO1-MM9), SO1-MM10

① Railway, housing, roads, resettlement of villages, and non-refinery related port items (e.g. 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 (e.g. oxalate, product, etc)
⑥ Assuming an extraction efficiency of about 50%, this means effectively a ratio of %TOC / % Avail. Aa of ~0.004
⑦ For a 1 Mt/y alumina refinery project: 30 Mt contained alumina, or in situ bauxite about 30x3=90 Mt
⑧ First quartile / Median of global bauxite mines excl. China

and "People" (effect on communities living close to or on the deposit).

4. **4A. Material Mined (=overburden + [non-beneficiated] bauxite) maximum 3.4 t/tA (dry basis)**: also a function of a number of characteristics (overburden/bauxite ratio, mining recovery, beneficiation recovery if applicable, % Available alumina and refinery alumina recovery). Global range is indicatively 2-25 t/tA. This criterion takes into account the overburden removed, the bauxite to the refinery, mining losses, and beneficiation tailings if applicable. Bauxite beneficiation / washing has several drawbacks: additional installations are required involving capex and opex, and environmental issues (water usage, tailings disposal). However applying bauxite beneficiation may be appropriate and needs to be considered on a case by case basis.

   4B. Residue to Disposal (= bauxite residue [incl. sand] + lime products) maximum 1.2 t/tA (dry basis): the bauxite residue ("red mud") leaving the refinery after removal of the Available alumina in the process (range of Available alumina content of globally processed bauxites is ~30-50%).This criterion is affected by % Available alumina and Reactive silica in the bauxite feeding the refinery, the alumina recovery in the plant, and lime and other products (e.g. filter aid) ending up in the bauxite residue. It impacts residue handling and disposal facilities, i.e. it has both economic (capex and opex) and environmental angles. Bauxite residue represents one of the main environmental issues related to alumina refining (refer sections 2.3 and 2.4) because of the large volume involved, its characteristics (very fine), and its basicity (due to the presence of NaOH in the adhering liquor). Globally bauxite residue ranges from indicatively 0.6-2.3 t/tA.

5. **Alumina in boehmite ($Al_2O_3.H_2O$ – alumina monohydrate) maximum 2 %**: below this number the large majority of available alumina is present as Gibbsite ($Al_2O_3.3H_2O$ – alumina trihydrate) requiring a low temperature (LT) for the digestion operation (~140-150°C), which has significant advantages: 1. Required temperature and pressure for steam to the digestion area in the refinery are at a low level, providing the opportunity to first use high pressure boiler steam for co-generation of steam and power positively impacting overall energy cost and thus opex, lower capex due to the requirement of lower-pressure vessels, simpler feed pumps, and less flash stages, and lower opex as a result of a lower power consumption and maintenance costs; 2. The total steam and power energy for a LT digestion plant is typically ~1-2 GJ/tA lower than for a high-temperature (HT) digestion refinery (~240-250°C), i.e. lower opex; and 3. Capex and maintenance costs of digestion and power & steam generation equipment are lower than would be required for HT digestion. At an alumina in boehmite of indicatively 6% economic considerations normally favor HT digestion.

   Another aspect is that below a certain boehmite in bauxite feed level, processing technology and operating conditions can be chosen such that boehmite does not dissolve in digestion and should not give rise to boehmite reversion (which would otherwise negatively affect efficiencies and operational conditions in the plant). Note that boehmite particle size, morphology, and impurities also affect reversion. In summary: high boehmite levels require HT digestion which negatively affects economics (increasing opex – energy and maintenance costs, and capex – high pressure refinery and powerhouse equipment), and the environment (higher energy consumption and emissions of greenhouse gases, NO_x and SO_x).

6. **Total caustic soda consumption maximum 75 kg (100% NaOH basis)/tA**: this criterion represents an important refinery opex component, mainly influenced by: 1. The ratio of % Available alumina to reactive silica in bauxite refinery feed which globally ranges from ~5-40 (a high ratio means a low caustic soda consumption) – Reactive silica in bauxite reacts with caustic soda and alumina in solution forming De-Silication Product (DSP) with a significant impact on caustic soda consumption and thus operating cost ("chemical soda loss"); 2. Physical soda losses with bauxite residue (affected by % Available alumina and alumina recovery in the refining plant); 3. The technology chosen in the bauxite residue wash circuit; and 4. Other soda losses (e.g. with oxalate, organics, and in product alumina). In environmental terms the energy required for the production of NaOH should also be taken into account. Global range: indicatively 10-175 kg NaOH/tA.

   Note that the advantage of very low reactive silica content in a bauxite w. r.t. caustic soda consumption may present a potential secondary processing disadvantage in LT digestion alumina refineries in that de-silicating the liquor may be more difficult, potentially affecting product quality and equipment scaling conditions. Bauxite test work needs to confirm the processing conditions required to control this aspect which could entail additional holding time in the Desilication facility and the necessity for additional equipment descaling, i.e. additional capex and opex.

7. **Ratio of % Extractable Organic Carbon (EOC) to % Available Alumina maximum 0.002**: below this number organic impurity removal may either occur sufficiently by natural removal processes (e.g. with bauxite residue) or by relatively simple removal methods (e.g. concentrating plant spent liquor in a salting out evaporator). At higher ratios extensive facilities may be required (oxalate / organics removal) at significant opex and capex. Global range is ~0.0003-0.007. In addition precipitation yield is affected, negatively increasing overall energy consumption and capex. An environmental aspect is that the removed impurities (e.g. as calcium compound or as mixed "salt" cake) need discarding, e.g. by combining them with the bauxite residue. Note: at an extraction efficiency of typ. 50%, the ratio % Total Organic Carbon (TOC) / % Available Alumina is ~0.004.

8. **Resource contained alumina minimum 30^+ years**: a key criterion for the selection of the production capacity of a greenfield alumina project is the size of the deposit. Although an alumina refinery may actually operate effectively for 40^+ years (refer e.g. Corpus Christi, Point Comfort, Woodside, Paranam, Stade, QAL, Gove, Kwinana, Pinjarra, etc), typically a project life of 30 years is applied to the significant investment of a greenfield bauxite & alumina project. In other words the resource on which the project is based should be able to sustain refining operations for such a period, i.e. for a 1 million tonne per annum alumina refinery project using 3 tonne of bauxite per tonne of alumina produced, the bauxite resource required would be of the order of 90 million tonnes. As the optimum refinery capacity may differ from location to location, the same applies to resource size. Due to its long lifetime, a bauxite and alumina project often plays an important role in the lives of the communities around the deposit and / or the refining plant.

Laboratory and field test work is required to establish several of the above discussed quality criteria such as disturbed acreage, material mined, residue to disposal, alumina in boehmite, caustic soda consumption, ratio of extractable to available alumina, etc.

3.3 Conclusions

Table 1 and its rationale illustrate that quality criteria for the evaluation of a bauxite resource span economic, environmental and social aspects, the "three pillars" of sustainable development. In other words sustainability in the context of bauxite deposits is not something abstract and isolated from "the real world", but can be qualified and quantified. The table also shows that economic and environmental (and in some cases social) aspects are intertwined most of the time. Putting it differently the economically more attractive deposits are often also more attractive in environmental terms.

Several of the criteria included in Table 1 are consistent with the issues for the upstream steps of the aluminium value chain from the Responsible Aluminium Scoping Phase RASP (e.g. waste management, land use and social resettlement for bauxite mining – refer section 2.3). And all of them are consistent with the long-term / strategic corporate sustainability targets of industry majors (refer section 2.4), implying the growing role of sustainability.

Based on the above it appears reasonable to assume that bauxite deposit quality in its widest sense, including sustainability, will play an ever more important role in future development decisions on greenfield bauxite and alumina projects.

4. References

1. The Global Mining Initiative, Address to Mining 2000, Melbourne September 20, 2000 by George Littlewood, Consultant WMC Resources Limited (Prepared in association with Tony Wells, BHP Minerals).
2. Breaking New Ground; The Report of the Mining, Minerals and Sustainable Development Project, MMSD May 2002.
3. MMSD + 10; Reflecting on a decade of mining and sustainable development, June 2012, A. Buxton, International Institute for Environment and Development (IIED).
4. Global Reporting Initiative (website https://www.globalreporting.org/reporting/sectorguidance/sector-guidance/mining-and-metals/Pages/default.aspx), RG & MMSS, Sustainability Reporting Guidelines & Mining and Metals Sector Supplement, RG Version 3.0/MMSS Final Version.
5. Vision 2050, The new agenda for business, World Business Council for Sustainable Development, February 2010.
6. Joint Report to the High-Level Panel of the Post-2015 UN Development Agenda, prepared by the UN Global Compact and the World Business Council for Sustainable Development, March 2013.
7. Responsible Aluminium Scoping Phase, Main Report, Track record, December 2010.
8. Responsible Aluminium Scoping Phase, Main Report Appendices, Track record, December 2010.
9. P.J.C. ter Weer, "Capital Cost: To Be or Not To Be" (paper presented at Light Metals 2007, Orlando, Florida), pp 43-48.
10. P.J.C. ter Weer, "Operating Cost – Issues and Opportunities" (paper presented at Light Metals 2006, San Antonio, Texas), pp 109-114.

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