Essential Readings in Light Metals: Alumina and Bauxite.
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Sustainable Bauxite Mining – A Global Perspective

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Abstract

In 2008 the International Aluminium Institute commissioned its fourth sustainable bauxite mining report with the aim to collect global data on the environmental, social and economic impacts of bauxite mining operations and their rehabilitation programmes. The report shows that bauxite mining has become sustainable and land area footprint neutral;it is a relatively small land use operation when compared to most other types of mining. All operations have clearly defined rehabilitation objectives, fully integrated rehabilitation programmes, and written rehabilitation procedures. The rehabilitation objectives can be summarized as follows: *"The bauxite mining operations aim to restore pre-mining environment and the respective conditions; this can be a self-sustaining ecosystem consisting of native flora and fauna or any other land-use to the benefit of the local community"*.
Almost 80% of the surveyed mines are ISO 14001 certified for environmental management. Bauxite miners are actively engaging with local communities to support development through employment, infrastructure, training & social programmes and compensatory packages. Displacement and resettlement issues are limited for the bauxite mining industry in total, but of high priority at the individual level for the people that need to be displaced and relocated.

Definition

Where percentages (%) of mines, operations or companies are indicated in the report, the values refer to the production weighted average/mean (PWA/PWM) that is based on the total reported bauxite production (TRB) of 122 million tonnes. TRB equals 66% of the 2006 world bauxite production (World Bureau of Metal Statistics, 2008). Therefore the indicated values should not be confused with the arithmetic average/mean that is less representative considering the differences in bauxite production per mining operation (range of 0.4 to 29.5 million tonnes per year per operation; PWA of 17.1 Mt).

Introduction

In 2008 the International Aluminium Institute (IAI) commissioned the fourth in its series of Bauxite Mine Rehabilitation Surveys (Bx IV Survey) with the aim to collect global data on the environmental, social and economic impacts of bauxite mining operations and their rehabilitation programmes.
Survey data for the year 2006 was received from fourteen major operations, producing 66% of the world's total bauxite production responded to the survey of year 2006 data.

The Bx IV Survey follows similar surveys of industry performance in 2003, 1998 and 1991. Reports on these surveys are available from IAI. This current report shows that bauxite miners continue to make substantial progress towards sustainable bauxite extraction and are continuing to improve their performance by employing environmental specialists and supporting environmental research and development projects.
Good environmental management before and during operations and post mining rehabilitation, which ensure that all potential land-use options are conserved, is one important way in which the industry is meeting its responsibility for protecting biodiversity. Operators are conserving and in many cases improving the natural capital in areas in which they mine, through the early identification of possible environmental impacts and through appropriate action to understand, monitor and minimise these impacts.
Bauxite mining is a relatively small land use operation when compared to most other types of mining. Since enough bauxite is available from a typical square kilometre of land mined to produce one million tonnes of aluminium metal, the land area mined annually throughout the world is only 30 square kilometre (equivalent to one half the size of Manhattan Island,
New York City).
Over the five year period 2002-2006, the average annual rehabilitation area of existing bauxite mining areas is equal to the average annual area being opened up. In this steady state environment, bauxite mining is "land area footprint neutral" and sustainable. The reporting mines have plans to rehabilitate more than 90% of the total area that was used for bauxite mining and infrastructure since operations commenced almost 70 years ago.
Almost 80% of the Bx IV Survey mines are ISO 14001 certified for environmental management. Mining leases and concessions are linked with rehabilitation conditions and the obligation to comply with government regulations. Many operations make rehabilitation the responsibility of individual production staff by including rehabilitation targets in their performance appraisals. All operations have clearly defined rehabilitation objectives, fully integrated rehabilitation programmes, and written rehabilitation procedures.
The displacement of people due to bauxite mining operations is limited, with only three of the 14 operations reporting that they displaced people reflecting the low population density in mining areas before commencement of bauxite extraction. Displacement and resettlement issues are limited for the bauxite mining industry in total, but of high priority at the individual level for the people that need to be displaced and relocated. It is also important to note that most of the mine workforce is recruited locally (66%) and a further 20% at the national level.

Bauxite mining personnel are actively engaging with local communities and working to ensure that the benefits of mining are shared locally, regionally and globally with present and future generations. Mining operations support the maintenance and development of local communities through employment, infrastructure, training & social programmes and compensatory packages.
It is fully expected that as future surveys are conducted to monitor progress in the bauxite mining industry, the journey toward sustainability will continue as member companies share best practices and learn from the successes of others.

1 Bauxite Mining & Production

1.1 Background Information

Aluminium is the most abundant metallic element in the earth's crust (over 7% by weight) and the third most abundant of all elements (after oxygen and silicon), with enough economically available reserves to supply at least another 300 years of current demand. However, because of its chemical reactivity it is mostly found in its oxidised form (approx. 250 different minerals exist) and almost never occurs in the elemental state. The most prominent group of aluminium containing minerals are the silicates, and the products of their weathering, the clays. With regards to aluminium production, it is the aluminium hydroxides which represent the most important compounds. The hydroxides and bauxite minerals gibbsite, boehmite and diaspore are the base raw material for primary aluminium production. They occur as a weathering product of low iron and silica bedrock in tropical climatic conditions.

1.2 Bauxite Production

The world's largest bauxite deposits (reserves) can be found in Guinea, Australia, Brazil and Jamaica. In 2006 the annual world production of bauxite amounted to 184 million tonnes (World Bureau of Metal Statistics, 2008). The 14 mines which responded to the 2006 survey produced 122 million tonnes and represent 66% of the respective annual world production. The smallest mine participating in the survey produced 0.4 Mt and the largest 29.5 Mt with a production weighted average (PWA) of 17.1 Mt for all reporting operations. Most of the reported bauxite (54%) was produced in Australia, followed by South America (19%), Africa (16%), the Caribbean (7%) and Asia (4%). The mines participating in the survey are located in Australia, Brazil, Guinea, Ghana, Jamaica, India and Greece.
The aluminium content of bauxite varies considerably with available/extractable alumina (Al_2O_3) content ranging from 31-52%. On a production-weighted basis, the average available alumina content is 41%. There is no clear relationship between production rates of bauxite and available alumina content. The largest producer has one of the lowest available alumina contents, indicating that other factors are more important in determining the viability and productivity of an operation.
Bauxite mines operate for long periods of time. The surveyed bauxite mines averaged 35 years of age with the oldest operation being commissioned in 1941 and the latest in 2001. The operations are expected to last on average for another 37 years (from now onwards; range: 12 to 117 years lifespan) with the earliest expected to terminate production in 2018 and the latest in 2123.

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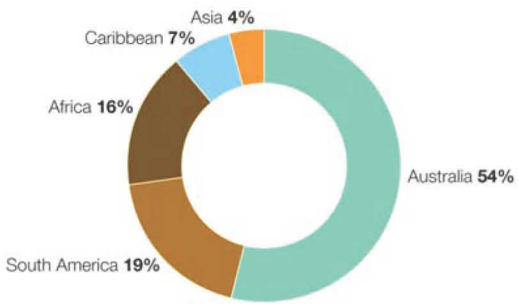
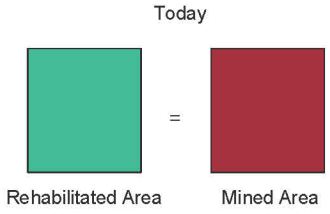
Location of IAI surveyed bauxite mining operations

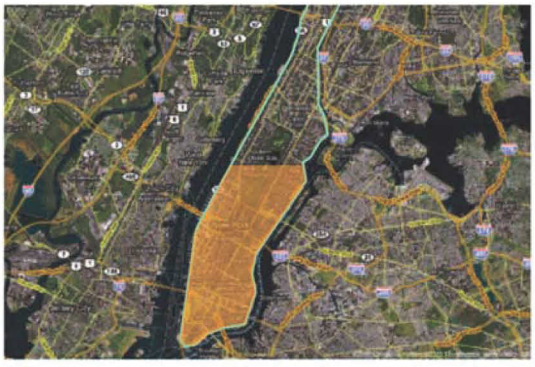


1.3 Land Use and Rehabilitation

Over the 15 year period from 1991 to 2006 bauxite mines extracted between 4.9 and 6.2 tonnes of bauxite per square meter of land used for mining. The annual differences highly depend on local geological conditions.
Of the average 162 m2 of land used for mining per 1000 tonnes of bauxite extracted over the five years from 2002-2006, a similar area has been rehabilitated. Approximately one tonne of aluminium metal is produced for each square meter of land area used for mining of the bauxite.



One fourth of the total used area was used for infrastructure and the remaining 75% for mining. A global extrapolation (scaled up from 66% of Bx IV coverage for 2006) leads to a total used area of only 30 km2 per annum with a similar amount of mined land being rehabilitated in the same year. This area is equivalent to one half the size of Manhattan Island, New York City.



Source: *Image courtesy of Google Maps*

1.4 Bauxite Properties

The average thickness of bauxite deposits varies from 2-20m with a production weighted average of 5m. An average 2m of overburden layer had to be removed before the bauxite deposits could be extracted. The overburden thickness ranged from 0.4-12m and the extracted bauxite had an average available alumina content of 41% that varied from 31-52%.

1.5 Processing of bauxite

Unlike other base metal ores, bauxite does not require complex processing, because most of the mined bauxite is of an acceptable grade or can be improved (beneficiated) by a relatively simple but not inexpensive process of removing clay. In many types of bauxite, clay is removed by some combination of washing, wet screening, cycloning and sorting. Beneficiating ore also reduces the amount of material that needs to be transported and processed at the refinery. However, the benefits of beneficiating need to be weighed against the amount of energy and water used in the process and the environmental impacts of the fine wastes produced and stored in tailing ponds. In 2006, three out of 14 plants beneficiated the bauxite at a local washing plant and two operations dried its bauxite before shipping.
After mining, the bauxite is refined into alumina using the Bayer process (refining). The majority of the alumina is then transformed into aluminium using the Hall/Heroult electrolytic process (smelting). However, some of the alumina is used in non-metallurgical applications. Two to three tonnes of bauxite are required to produce a tonne of alumina and four to six tonnes of bauxite for the production of one tonne of aluminium metal.

1.6 Energy Consumption

Bauxite mining requires only a small amount of energy compared to refining of bauxite and electrolytic reduction of alumina. Diesel fuel (69%) and fuel oil (24%) provide the bulk of the energy used to mine and transport the bauxite. The average energy consumption amounted to 153 MJ per dry tonne of mined bauxite (range: 40-470 MJ/tonne). On average each tonne of bauxite had to be transported 54km from the point of extraction to the shipping point or local refinery stockpile (range: 11-240km).
Mine operators have adopted a number of strategies to use energy more efficiently and to reduce emissions. These strategies include:

- Purchase of larger, more energy efficient mining equipment and trucks
- Improved maintenance of mining and transport machinery
- More efficient use of equipment by optimising truck cycle times and reducing idling and waiting times
- Reduction of haul distances for overburden storage
- Use of downhill regenerative cable belt conveyors to transport bauxite
- Change to lower emission fuels such as natural gas where possible

2 Mine Rehabilitation

Rehabilitation aims at returning the original ecosystem as close as possible, in terms of structure, function and dynamics. Before mining commences the millable lumber and soil is removed from the original area. The soil rich in organic matter is stored and used for the reforestation afterwards.
It is intended to reproduce the diversity of the original ecosystem (flora & fauna). The reporting mines envision rehabilitating more than 90% of the total area that was used for bauxite mining and infrastructure.
Most operations rehabilitate used areas progressively as they become available. Currently, 53% of the used areas have already been rehabilitated while the remaining 47% are still being mined or devoted to infrastructure purposes. During the most recent five years (related to 2006 production) 163 m2 per 1000 tons (m2/kt) of produced bauxite has been rehabilitated.
Mine rehabilitation (163 m2/kt) equals bauxite mining (162 m2/kt) and leads to a steady state environment in which newly mined areas are balanced by rehabilitation of existing mining areas. Bauxite mining has therefore reached a stage where the land area footprint remains constant. Bauxite mining under steady state condition is "land area footprint neutral" and sustainable.
The following pictures show the development sequence of rehabilitation areas at the MRN mine in Brazil. During the 10 year period from 1992 to 2002 clear progress towards successful rehabilitation was made and the area is getting very close to its original state before mining operations commenced:

During rehabilitation in 1992

Rehabilitation areas in 1997

Rehabilitation areas in 2002

2.1 Pre- and Post Mining Land Use

Before commencement of bauxite mining approx. half of the original vegetation was native forest (mostly hardwood), followed by tropical rain forest (24%), farming (11%) and pasture (10%). Agricultural crops (3%) were less occurring.
When asking the mining operations for their planned post-mining land use after completion of rehabilitation, the percentage of native forest increased by 11% amounting to 60%. The share of tropical rainforest (forest with a minimum rainfall between 1750-2000 mm/year which is located in the tropics) will remain almost constant (24% pre- and 23% post-mining).
The post-mining land use for farming declined from 11% before mining to 2% after. It seems that the difference of 9% is related to a planned land use change from farming towards native forests. The ratios for pasture, agricultural crops and other forms of land use are not expected to change much between original and post-mining land use.

2.2 Case Study: Bauxite Mine Rehabilitation in Brazil

The Mineração Rio do Norte (MRN) mine in the Amazon reported the regular sighting of a puma in one of the rehabilitated areas. This observation is a good occurrence since the puma sits at the top of the food chain and is a biological indicator for an intact ecosystem. It therefore indicates that biodiversity at all levels below is maintained. MRN has many success criteria for understanding the status of rehabilitated areas.

Puma in rehabilitation area

MRN has a very sophisticated rehabilitation program in place which includes an epiphytes project that involves the rescue, classification and multiplication of a variety of epiphytes (araceae, bromeliads and orchids). The epiphytes are collected in clearing areas, maintained in plant nurseries and then introduced to the rehabilitation area after reforestation was successful and reached a mature state.

2.3 Rehabilitation Workforce

To carry out world-class rehabilitation requires a workforce with environmental expertise. The Bx IV Survey respondents engaged an average 21 full time rehabilitation specialists (as employees/contractors) who spend more than two thirds of their time on rehabilitation. Rehabilitation personnel covered the following professions:

agricultural scientists	horticulturists	earth scientists
soil scientists	zoologists	biologists
foresters	hydrologists	geomorphologists
environmental	conservation	rural development
managers	biologists	scientists
botanists	environmental scientists	natural resource managers

Rehabilitation personnel and their environmental expertise

3 Social Dimension & Local Communities

Bauxite miners are investing in measures to provide social and economic benefits to local, regional and global communities. They aim to ensure that the wealth generated by mining is shared throughout the community and will also benefit future generations.

3.1 Social and Economic Benefits of Bauxite Mining

Mining operations engage with local and indigenous communities and generate net benefits by:

- Provision of well paid-employment under conditions that comply with accepted labour standards
- Provision of education and training programmes
- Development of local industries and businesses
- Support of community initiatives and social activities
- Investment in infrastructure development that benefits the communities
- Provision of health and sanitation programmes (malaria prevention, vaccination)
- Provision of compensation for those who are disadvantaged or displaced by the mining operation
- Federal, state and municipal tax payments

The 10 operations that reported on this question, representing 78% of total Bx IV Survey production, pay wages at the mine equal to the national average or are even higher.
Women generally constitute a small proportion of the workforce in the mining industry that is traditionally biased towards a male workforce. On average women comprise 10% of the workforce in bauxite mining.

3.2 Population Density, Displacement and Origin of Mine Workforce

Most of the bauxite mines are located in areas that were sparsely populated prior to commencement of mining. 76% of bauxite was produced in areas that inhabited less than 5 people per km2 whereof 37% was populated by only 1 person per km2. 23% of bauxite was mined on areas inhabited by 26-100 people per km2.
The displacement of people due to bauxite mining operations is limited, with only three of the 14 operations reporting that they displaced people reflecting the low population density in mining areas before commencement of bauxite extraction. Displacement and resettlement issues are limited for the bauxite mining industry in total, but of high priority at the individual level for the people that need to be displaced and relocated. It is also important to note that most of the mine workforce is recruited locally (66%) and a further 20% at the national level.

3.3 Involvement of Local Communities

Local communities need to be empowered when decisions about natural resource management that affect them are made. Consultation on bauxite mining issues is important in reducing the negative social impacts of mining at many operations. A majority

of operators hold community consultation meetings and maintain formal links with community leaders to ensure that communities are informed about and have input to significant decisions. 11 operations, representing 84% of total reported bauxite production, have formal procedures in place to deal with complaints from neighbouring communities.
On production weighted average, bauxite mining companies spend more than US$ 400 000 per operational year to support community programs which address:

- Medical care
- Provision of safe water supply and managed wastewater systems
- Provision of managed solid waste facilities
- Infrastructure development
- Cultural development and arts
- Preservation of local culture
- Crisis counseling (drugs, alcohol)
- Schools
- Youth support programs
- Scholarship and apprenticeship programmes

4 Environmental Management

A sustainable mining operation maintains the natural capital of the area in which it operates via a sound environmental management system in order to reduce the environmental impact of the mining activities. Successful rehabilitation and environmental management ensures that bauxite mining is a temporary land-use that does not compromise other land uses in the long-term.

4.1 Environmental Management and Rehabilitation

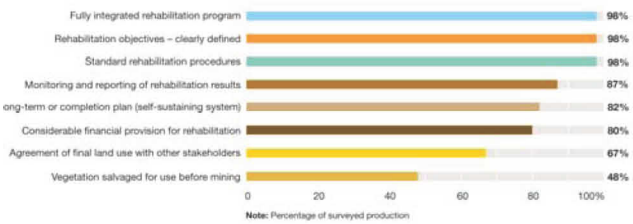
Almost 80% of the Bx IV Survey mines are ISO 14001 certified for environmental management. *Mining leases and concessions are linked with rehabilitation conditions and the obligation to comply with government regulations.* Many operations make rehabilitation the responsibility of individual production staff by including rehabilitation targets in their performance appraisals. All operations have clearly defined rehabilitation objectives, fully integrated rehabilitation programmes, and written rehabilitation procedures. The rehabilitation objectives can be summarized as follows:

"The bauxite mining operations aim to restore pre-mining environment and the respective conditions; this can be a self-sustaining ecosystem consisting of native flora and fauna or any other land-use to the benefit of the local community".

More than 80% of the Bx IV Survey operations have a long-term or completion plan for their mining area, which aims to leave a self-sustaining system with realistic land-use options in place after mining activities have been completed. Rehabilitation practices and efforts are based on a variety of sources including:

- Local, national and international NGOs
- Local, national and international company standards
- Government standards
- Local and national community expectations

80% of reporting mines have made considerable financial provisions, devoting human resources, know how, material and equipment for the rehabilitation of land that was used for mining and associated infrastructure, final decommissioning and mine closure. Implementing environmental management systems is just as much time and cost intensive. 82% of mines maintain an environmental awareness and training program for all employees and contractors who are involved in rehabilitation.



4.2 Flora & Fauna Protection

Two-thirds of mine operators have agreed a final land-use for the rehabilitated areas with stakeholders having an interest in conservation (stakeholders such as traditional owners, landowners, federal, state and municipal government agencies and regulators, local communities and NGO's). Monitoring and reporting programmes are in place at 87% of the mines which formally assess the strengths and weakness of their rehabilitation. Most of these operations have established plots that will be repeatedly monitored over time to study the ecology and development of rehabilitated areas. Half of the mine operators salvage the original vegetation for use before they commence mining and clearing the respective area. Other measures that are taken by companies to protect areas of native flora & fauna include:

- Pre and post mining flora and fauna surveys
- Use of native plant species for rehabilitation
- Operation of plant nurseries to propagate and grow native plant species
- Relocation of plants growing in cleared areas
- Compensation measures: establishment of flora reserves on other company-owned land
- Leaving strips or islands of native vegetation within mining areas
- Provision of financial and other aid to groups with an interest in conservation
- Minimising unnecessary clearance
- Measures to retain wildlife habitat as wildlife reserves and wildlife corridors
- Reconstructing fauna habitats using rocks and logs taken from areas being cleared for mining
- Providing fauna nesting boxes in rehabilitated areas
- Fauna recolonisation (birds, invertebrates)
- Wildlife monitoring programmes (vertebrates, invertebrates)

Plant nursery to propagate and grow native plant species/seedlings

4.3 Soil Management

Sustainable mining operations protect and restore the biodiversity of the areas they affect. Restoring pre-mining biodiversity requires areas to be protected from erosion and for the original topsoil to be managed to retain its value as a seed source and growing medium. Therefore operations separate the topsoil from the remaining overburden and retain it for use in rehabilitation. The species that are established on the rehabilitation area are from returned topsoil (57%), plant seedlings (24%) and broadcast seeds (19%).

Reshaping of mined land blends mined areas into the surrounding landscape, reduces the likelihood of erosion, by reducing slope angles and lengths, and allows natural drainage patterns to be re-established. Despite being located in areas with heavy seasonal rainfall, most operations rate the erosion risk at their mines as low.

This is due to effective mitigation measures, which prevent soil loss during clearing, mining and stockpile storage. Erosion control measures include:

- Building of structures to retain and control runoff water (contour ripping, terracing, contour banks, dams, drainage design, silt traps, sumps, settling ponds)
- Storage of topsoil and overburden on areas with shallow side slop to prevent erosion and soil degradation
- Quick revegetation of used/backfilled areas and soil stockpiles with soil binding species like lemon grass (hydro seeding)
- Vegetation cover through mulching
- Soil handling at particular times of the year with little erosion potential (wind, temperature, precipitation)

4.4 Environmental Legislation and Regulations

Most of the production from the Bx IV Survey (76%) comes from mines that assess the environmental impact (EIA) of their activities before commencement of mining. This assessment includes identification, prediction, evaluation and mitigation of the biophysical, social, and other relevant effects of the planed project prior to licensing and closing a contract. After an EIA, precautionary measures are applied to prevent and limit the impact of a project to the natural environment. The EIA includes the following:

- Monitoring of surface and groundwater quality leaving the mining area
- Impact assessment of mining activities on freshwater users (water supply, fishing, irrigation, recreation, industry, domestic)
- Baseline and impact assessment of terrestrial and aquatic biology (flora & fauna)
- Dust and noise level monitoring and impact assessment
- Assessment of social impacts and community engagement

According to national/international environmental legislation and regulations, 84% production of the Bx IV Survey comes from mines where an environmental license is required during operation and rehabilitation plans have to be approved by an environmental or land management agency; a certificate is issued for successful rehabilitation.

4.5 Mitigation Measures

Strategies to mitigate environmental and social impacts of bauxite mining include:

- Noise mitigation measures by monitoring and modelling noise levels, provision of buffer zones, timing of operations, modification of equipment, change of mining and blasting methods
- Control of dust levels by watering, road maintenance and speed limits
- Limited blasting times to reduce frequency
- Construction of settling ponds and other drainage control structures
- Rehabilitation of used areas as quickly as possible
- Procedures to minimise hydrocarbon and other spillages
- Research and Development Projects

4.6 Research and Development (R&D)

84% of production from the Bx IV Survey comes from mines that undertake or support environmental research focussing on:

- Hydrology
- Increasing biodiversity on rehabilitated areas including a gene sanctuary
- Reduction of rehabilitation cycle by grasses, legumes and fast growing trees
- Making rehabilitation more attractive for wildlife
- Improving soil management and ripping techniques
- Vegetation succession and resilience to disturbance
- Soil development and improvement
- Nutrient cycling and recolonisation of soil fauna and mycorrhiza
- Finding appropriate indicators of rehabilitation success and sustainability

Continuous improvement in environmental management requires personnel to keep abreast of developments in the field. Industry publications, government publications, scientific conferences and internet are ranked as the preferred medium by which specialist environmental staff enhances their knowledge of environmental best practice. Industry seminars and scientific papers are also ranked highly. Mining operations often exchange knowledge by visiting each other's operation and sharing of best practice on rehabilitation and environmental management.

4.7 Promotion of Environmental Management

64% of production from the Bx IV Survey comes from mines that provide videotapes and handouts for distribution that show specific information on mine rehabilitation and environmental management. 84% comes from mines that offer plant visits and tours to the public and 42% from mines that have even been recognised as outstanding or innovative regarding their best practice and environmental management activities.