National Research FLAGSHIPS
Light Metals

CSIRO

Management of Bauxite Residue: Priority Research Areas

Greg Power, Markus Gräfe and Craig Klauber

CSIRO Document DMR-3611
May 2009

Asia-Pacific Partnership Project ATF-06-3:
"Management of Bauxite Residues"

ASIA-PACIFIC PARTNERSHIP ON CLEAN DEVELOPMENT & CLIMATE

Australian Government

www.csiro.au

Parker Centre

Enquiries should be addressed to:
Dr. Craig Klauber
CSIRO Minerals
PO Box 7229
Karawara WA 6152
AUSTRALIA
e-mail: craig.klauber@csiro.au

Copyright and Disclaimer

Important Disclaimer

CONTENTS

List of Tables

EXECUTIVE SUMMARY

This report addresses Item 7 of Project ATF-06-3 on the Management of Bauxite Residues for the Department of Resources, Energy and Tourism (DRET), Commonwealth Government of Australia, on behalf of the Asia-Pacific Partnership on Clean Development and Climate.

A priority list of the most promising research areas is provided, based on the knowledge gaps identified. Full details of the background information, process and outcomes of the literature reviews and the development of the priority list are available in the related reports[1].

The research priorities developed in this project form the basis of a comprehensive research and development programme required to support the identification, development and implementation of new and improved options for utilisation of bauxite residue for the future. To comprehensively address the key knowledge gaps, a larger Research and Development (R&D) programme will need to be developed in consultation with the alumina industry, governments participating in the APP, and research providers.

CSIRO Minerals is well placed to coordinate the overall RD&I Plan and to lead a number of key research projects as part of Australia's contribution to the APP process. Involvement of other research groups and partnerships with industry participants will be essential to the success of individual projects and the programme overall.

Input and participation is invited and encouraged, starting with feedback on the issues raised and suggestions made in this and the associated reports. Dr Craig Klauber is the key contact for all matters related to this project, and Dr Markus Grafe is the contact for knowledge management issues, in particular the database (BRaDD). In particular, comment is invited on the preliminary project list and participants are encouraged to access the Bauxite Residue and Disposal Database (BRaDD) on line, and also to contribute comments and information.

[1] The accompanying CSIRO reports: DMR-3608, DMR-3609 and DMR-3610

1. INTRODUCTION

1.1 Scope

This Improvement Roadmap is part of the ATF-06-3 project on the Management of Bauxite Residues for the Department of Resources, Energy and Tourism (DRET), Commonwealth Government of Australia, Commonwealth Government of Australia, and represents completion of Item 7 in the schedule of Contract for the Provision of Services number 2490. As such it also represents part of the overall commitment of the Australian Government toward the Asia-Pacific Partnership on Clean Development and Climate (http://www.app.gov.au/). China and India are also involved in research components of the ATF-06-3 project. Please also refer to the three parallel review documents that relate to Items 3, 4 and 5 in the aforesaid Contract:

DMR-3608 Review of bauxite residue storage practices (Item 3)
DMR-3609 Review of bauxite residue reuse options (Item 4)
DMR-3610 Review of bauxite residue alkalinity and associated chemistry (Item 5)

1.2 Purpose of the Asia-Pacific Partnership (Clause 6.2)

The Asia-Pacific Partnership on Clean Development and Climate (APP) brings together the United States, Canada, China, Japan, Korea, India and Australia to address the challenges of climate change, energy security and air pollution in a way that encourages economic development and reduces poverty. The APP represent around half the world's emissions, energy use, GDP and population, and is an important initiative that engages, for the first time, the key greenhouse gas emitting countries in the Asia Pacific region. With its focus on the development, deployment and transfer of cleaner more efficient technologies, the APP is also unprecedented in the way business, government and researchers have agreed to work together. The APP is also the first time that industry has been afforded an opportunity as equal partners in global climate change discussions.

The objectives for the APP include to:

- *Meet the growing energy needs, reduce poverty and achieve the development goals of partner countries and reduce greenhouse emissions and intensity of partner economies;*
- *Strengthen cooperative efforts to effectively build human and institutional capacity in partner countries;*
- *Actively engage the private sector with considerable marshalling of financial, human and other resources from both public and private sectors;*
- *Demonstrate substantial practical action in the near term as an approach to addressing climate change;*
- *Develop and deploy clean fossil and renewable energy technologies and practice including longer-term transformational energy technology; and*
- *Develop and disseminate best management practice and technology in:*

- *Aluminium, steel, cement and coal mining industry sectors*
- *Energy efficiency in building appliances, and*
- *Power generation and transmission.*

The Project aims to address the high volume of bauxite residue (red mud) produced during the processing of alumina from bauxite. It will identify, develop and deploy technologies and practices for the alternative use of bauxite residues or improved storage practices. Thus the project will enable the development of best practice residue management options to reduce the reliance on stockpiling and storage, or to make stockpiling and storage more environmentally acceptable. ˆ

2. ITEM 7: Priority list of research and areas of most promising outcomes

Bauxite residue has been continuously produced since the inception of the alumina/aluminium industry in the late nineteenth century. We have estimated that the global inventory of bauxite residue reached 1 billion tonnes in 1985, 93 years since the establishment of the first Bayer process plant. This inventory grew to 2 Bt by 2000, a doubling time of only 15 years. The inventory was 2.7 Bt by 2007, growing at 119 million tonnes per annum. It will probably reach 4 Bt before 2015.

Despite a long-standing recognition of the disadvantages associated with residue storage, it has nevertheless continued to be the preferred solution on balance of economic, environmental and social considerations. Large-scale storage of bauxite residue is a practical reality for the foreseeable future. In light of that there is a need to continuously improve means of storage and remediation. However the residue also provides the opportunity to create value through utilisation of it as a resource, either as a feedstock for the production of other materials, or as a product in its own right. In the "triple bottom line" sense [1], this is in principle is a more sustainable outcome than storage. In order to have a significant impact on the rapidly growing global inventory of bauxite residue, ***large tonnage utilisation options are needed***.

Detailed literature reviews identified four major improvement themes associated with bauxite residue: improved storage, improved rehabilitation, and value creation in either mineralogical or metallurgical applications. The R&D programme required to achieve progress on each of these themes is arranged into five priority project areas: knowledge management, fundamental chemistry & physics, immediate value opportunities, bioremediation, and industrial synergies. The inter-relationships are shown in Table 1.

Table 1: Relationship of priority project areas to major improvement themes. ✓indicates that the indicated project area supports the corresponding improvement theme. The type of support is designated research (R), development (D) or implementation (I).

Mapping of Project Areas to Major Improvement Themes					
PRIORITY PROJECT AREAS	MAJOR IMPROVEMENT THEMES				
	Improved Storage	Improved Rehabilitation	Value Creation		
			Mineralogical Applications		Metallurgical Applications
			Construction & Chemical	Environmental & Agronomic	
Knowledge Management: BRaDD (R)	✓	✓	✓	✓	✓
Fundamental Chemistry & Physics (R)	✓	✓	✓	✓	✓
Immediate Value Opportunities (DI)	✓	✓	✓	✓	
Bioremediation (RDI)		✓		✓	
Industrial Synergies (RDI)			✓	✓	✓

2.1 Major improvement themes and needs

2.1.1 Improved storage

Prior to 1980, most of the global inventory of bauxite residue was held in lagoon-type impoundments. Since 1980 the trend has been towards dry stacking to reduce the potential for leakage of caustic liquor to the surrounding environment, reduce the land area required, and maximise the recoveries of soda and alumina. Dry stacking relies on deposition of the residue at a moisture content of <50% and subsequent dewatering to <30% moisture over an extended period (several years).

The next step in the improvement process could be through deposition of the residue at <20% moisture, which is termed dry disposal. Treatment of residue for discharge as a dry, granular material of low soda content has been demonstrated using hyperbaric steam filtration. Large-scale deployment of this breakthrough technology to bauxite residue may be possible with implementation support.

The quantity and quality of information obtainable from publicly-available sources on storage practices is limited and difficult to access. The creation of an up-to-date, comprehensive database on storage practices and technology would an invaluable tool for planning and technology transfer to accelerate the development and deployment of improved practices globally.

2.1.2 Improved rehabilitation

The most important barrier to remediation, re-use and long term sustainability of bauxite residue management is its high alkalinity. The alkalinity of bauxite residue is a result of a complex mixture of solid-state and solution phase interactions. Better understanding of these interactions is required to support progress in the development of sustainable bauxite residue management and re-use options. Additional research is therefore needed on the chemistry and technology of residue neutralisation.

2.1.3 Value creation

To successfully transform residue from a waste to be disposed at a cost, to a product to create overall value, will take not only the development of technological solutions, but barriers related to cost, risk, volume and performance factors will have to be overcome. This could possibly be stimulated on a case-by-case basis by, for example, direct government support and/or regulation, collaborative arrangements between industry, community and government, industrial synergy projects, or any combination of these.

As a basis for planning, the drivers and barriers have been organised into three opportunity areas as follows:

Opportunity area 1: Construction & Chemical Applications
- 1.1: Civil & Building Construction
- 1.2: Catalyst Support or Adsorbent
- 1.3: Ceramics, Plastics, Coatings or Pigments

Opportunity area 2: Environmental & Agronomic Applications
- 2.1: Water & Waste Treatment
- 2.2: Gas Scrubbing Agent
- 2.3: Agronomic Applications

Opportunity area 3: Metallurgical Applications
- 3.1: Recovery of Major Metals
- 3.2: Steel Making & Slag Additive
- 3.3: Recovery of Minor Metals

The Risk Management issues have been discussed in DMR-3609.

2.2 Project areas: Research, Development and Implementation

2.2.1 Knowledge management - BRaDD

A major improvement in the availability of relevant information relating to bauxite residue is essential to the development of comprehensive management plans and mutually beneficial technology transfer within the APP. The sources of publicly available information on bauxite residue include a predominance of conference proceedings and other publications outside the mainstream academic literature. This makes it very difficult to extract and examine information in a systematic and comprehensive manner. This gap is being addressed with the development of the Bauxite Residue and Disposal Database (BRaDD) which will provide a step change

improvement in the comprehensiveness and availability of information relating to bauxite residue. The availability of this level of information, and the ability to readily interrogate it, will be invaluable as a research and planning tool. Collaboration with industry participants to facilitate input of company data and information into BRaDD will be essential if its full potential to all stakeholders is to be realised.

BRaDD will address knowledge management needs across all four improvement themes. It is being developed by CSIRO as a web-based tool to enable ready access to registered users. CSIRO proposes to maintain and continue to develop the capability and data capacity of BRaDD, and will invite participation from industry participants to provide data which will then be stored and managed according to set protocols to the benefit of all users.

2.2.2 Fundamental chemistry and physics

A major improvement in the understanding of alkalinity and associated chemistry related to bauxite residues is essential to provide the basis for major improvements in the management and utilisation of bauxite residues. A programme of fundamental research has been outlined to fill this knowledge gap, and to enable the development of effective thermodynamic and kinetic models of the neutralisation behaviour of bauxite residues. CSIRO proposes to lead the chemistry component of this research effort at Waterford (Western Australia), with assistance from other groups in CSIRO and elsewhere as required.

The development of a range of large-scale construction and agronomic applications for residue throughout the world will require a step change improvement in a number of areas of basic knowledge. In particular, leaching behaviour, the concentrations and speciation of trace metals and naturally occurring radioactive materials, physical and mechanical properties, and conformance with applicable environmental, safety, engineering and construction standards will all need to be investigated and systematised. A list of research projects is outlined to address these knowledge and technology gaps. CSIRO would propose to co-ordinate this research from Waterford, using internal and external resources as appropriate.

2.2.3 Immediate value opportunities

There is the opportunity to realise value in the short term by implementing technology-ready solutions to reduce storage and/or rehabilitation costs, or to create new value through the utilisation of residue as a resource or product.

Hyperbaric steam filtration is one technology with the potential to create a major beneficial change in bauxite residue management in the immediate future. This method has been demonstrated successfully for bauxite residue at a pilot scale, and large-scale hyperbaric filtration has been installed at the Alunorte plant in Brazil for the filtration of bauxite. The achievement of moisture contents of <20% by this or other technology could enable significantly better storage and rehabilitation of bauxite residue and facilitate a range of residue utilisation possibilities.

Support for deployment of utilisation options that have already been demonstrated technically is suggested as a means of stimulating broader interest in promising approaches. Such projects would need to fit a set of criteria including the potential to

consume a large tonnage of residue, use by a willing customer in the refinery locality, using low cost technologies that are available or can be made available in a short time. A number of opportunities have been identified for the application of residue in construction applications. Implementation of specific opportunities in the APP region could have a significant impact on the rate of residue utilisation. Specific applications include:

- Additive to Portland cement
- Component in light-weight aggregates
- Development of sand fraction as a construction material
- Component of bricks and blocks
- Development of controlled low strength materials

2.2.4 Bioremediation

Bioremediation has the potential to revolutionise future residue storage management. The concept is an extension of some approaches that have been trialled previously but not fully developed. It adapts well known agronomic practices to create a sustainable solution for long term residue management in which plants, microbes and other organisms accelerate natural processes to convert residues into functioning soils. CSIRO is well-placed to lead this research effort at Waterford (Western Australia), with assistance from other groups in CSIRIO and elsewhere as required.

2.2.5 Industrial synergies

The possibility of using bauxite residue as a feedstock for the production of mineral and metal values has been suggested in a number of studies, however no viable process has ever been implemented. An evaluation of the possible technological routes in the context of regional socio-economic settings is required, with particular reference to the opportunities for synergies between industries. Other synergies that could be explored include the combination of bauxite residue with other by-products such as fly ash as ingredients for construction materials, and the use of bauxite residue as a component of fertilizers [2].

2.3 Preliminary project list

A preliminary project list has been developed on the basis of the detailed literature reviews and is summarised in Table 2. It is intended that this list form the basis of an initial project portfolio to be initiated as soon a practical. In support of this, CSIRO is well advanced with the project on knowledge management (BRaDD development) , which has been largely supported by internal CSIRO funding. CSIRO has also commenced work relevant to Projects 2.1 and 2.2. CSIRO Minerals is well-placed to co-ordinate and participate in much of the proposed project portfolio, but increased engagement with the APP partners is essential for success.

Table 2: Preliminary Project List for the development of improved bauxite residue management (CSIRO-M = CSIRO Minerals; CSIRO-L&W = CSIRO Land & Water).

PRELIMINARY PROJECT LIST		
Project number	Description	Potential Contributors
Opportunity area 1: Knowledge management		
1.1	BRaDD development	CSIRO
Opportunity area 2: Fundamental chemistry & physics		
2.1	Chemistry of leaching and neutralisation	CSIRO, universities and other research providers
2.2	Thermodynamic & kinetic models of neutralisation	CSIRO, universities and other research providers
2.3	Dissolution behaviour of Bayer solids	CSIRO, universities and other research providers
2.4	Hydrological modelling	CSIRO, universities and other research providers
Opportunity area 3: Immediate value opportunities		
3.1	Low moisture residue, eg by hyperbaric filtration	Filter manufacturers, industry partners
3.2	Carbon sequestration potential	CSIRO, universities and other research providers
3.3	Carbonation by stack gas	CSIRO, engineering consultants, industry partners
3.4	Liner integrity & longevity	CSIRO, engineering consultants, industry partners
3.5	Civil construction applications	CSIRO, engineering consultants, industry partners
3.6	Utilisation as soil additive	CSIRO, universities and other research providers
3.7	Definition of liability issues for producers & users	CSIRO, universities and other research providers
3.8	Future liability cost model	CSIRO, universities and other research providers
Opportunity area 4: Bioremediation		
4.1	Fundamentals of bioremedation of bauxite residue	CSIRO, universities and other research providers
4.2	Amendments for development of soil structure	CSIRO, universities and other research providers
4.3	Vegetative covers	CSIRO, universities and other research providers
4.4	Best practice agronomy	CSIRO, universities and other research providers
Opportunity area 5: Industrial synergies		
5.1	Evaluation of regional synergy opportunities	CSIRO, universities and other research providers

ACKNOWLEDGEMENTS

This project received funding from the Australian Government as part of the Asia-Pacific Partnership on Clean Development and Climate

The views expressed herein are not necessarily the views of the Commonwealth, and the Commonwealth does not accept responsibility for any information or advice contained herein.

Development of BRaDD has been an initiative of the CSIRO Light Metals Flagship.

REFERENCES

1. Elkington, J., *Cannibals With Forks: The Triple Bottom Line of 21st Century Business*. Capstone Publishing Ltd: Oxford, 1997; p 402.
2. van Beers, D.; Corder, G.; Bossilkov, A.; van Berkel, R., Industrial symbiosis in the Australian minerals industry - The cases of Kwinana and Gladstone. *Journal of Industrial Ecology* **2007,** *11*, (1), 55-72.

Contact Us
Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au

Your CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.