Alumina Technology Roadmap

International aluminium institute
Bauxite and alumina Committee
2010 Update

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Roadmaps should be living documents and updated as technology developments and industry sectors evolve. The first *Alumina Technology Roadmap* was published in November 2001, following an industry-wide workshop coordinated by AMIRA International. The workshop and the Roadmap publication, facilitated by Energetics, Incorporated, USA, resulted from collaboration between the Aluminum Association Inc., U.S. Department of Energy, Office of Industrial Technologies (DOE/OIT), the Australian Department of Industry, Science and Resources and the nine alumina companies directly involved. This *Alumina Technology Roadmap* built on the *Technology Roadmap for Bauxite Residue Treatment and Utilisation*, published in February 2000, and the *Aluminum Industry Technology Roadmap* which was updated in February 2003.

A minor update of the A*lumina Technology Roadmap* was undertaken in early 2006.

Experience over recent years in implementing the outcomes of the *Alumina Technology Roadmap* clearly points to the need to substantially review its contents and produce an update identifying the technological demands the alumina industry is facing over the next 15-20 years. This will provide a vehicle for communicating the future needs of the industry and focus the efforts of research laboratories, supplier companies and universities on critical issues.

The alumina industry has changed – and this process will continue, as will demands for improved performance from both internal and external forces. Metallurgical grade alumina production has risen from 48 million tonnes in 2000 to 80 million tonnes in 2010 – over 65% growth. New sources of bauxite and new operating parameters also bring new challenges and new opportunities.

Significant new alumina capacity has been added in the South American, Asian and Oceania regions, but dwarfed by the dramatic growth in Chinese capacity and production. From 4 million tonnes in 2000 to 28 million tonnes in 2010, China has jumped to become the world's leading alumina producer accounting for over 35% of global metallurgical grade alumina production.

This update of the *Alumina Technology Roadmap* has for the first time benefited from collaboration with the Chinese alumina industry. A meeting of the IAI Bauxite & Alumina Committee was held in Zhengzhou, China in April 2010, hosted by Chalco's Zhengzhou Research Institute. The meeting attracted a high level of participation from the Chinese alumina industry, with over 140 attendees, including participants from 21 of the 34 Chinese alumina refineries. From questionnaires completed by Chinese participants and an interactive workshop session, a number of key themes were identified for further examination including mine rehabilitation, residue management and use, alumina production from high sulfur bauxite, bauxite beneficiation, energy efficiency and alternative technologies for alkali and alumina recovery from bauxite residues. This work is being continued with a further meeting of the BAC set for late November again in Zhengzhou, China to progress issues identified in this *Roadmap*.

Dr Tony Bagshaw of Chemical Systems Pty Ltd was commissioned by the IAI, on behalf of the IAI Bauxite & Alumina Committee (BAC), to prepare this Roadmap update – and has worked closely with members of the BAC and the Alumina Technical Panel (ATP) in its preparation.

The IAI and Dr Bagshaw appreciate the positive support and contributions by the many industry and external stakeholders to this process.

Dave Olney
Co-Chair – IAI Bauxite & Alumina Committee

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1. Introduction

The objective of this *Alumina Technology Roadmap* is to identify the alumina industry's collective vision of its operating environment in some 15-20 years time, and the goals it must achieve to reach this vision. The *Roadmap* focuses on the production of (smelting grade) alumina as feedstock for aluminium metal production.

In the wider context the alumina industry continues to face similar issues as most other global commodity producers: social and environmental considerations, the challenge of sustainable operations, the image of a responsible industry, and competition from substitute materials. Individually, each producer is addressing these challenges; this is after all a competitive industry and significant gains in certain Bayer process technologies (such as liquor productivity/precipitation yield) can deliver substantial business advantages.

The *Roadmap* recognises that alumina producers compete in the marketplace; achieving some goals will, by their very nature, be competitive. However, some challenges are best dealt with by an industry sector above and beyond the direct competitive environment. One key outcome of a technology roadmap is identifying these collaborative areas and the steps that must be taken to achieve industry-wide goals.

Both continuous improvement through incremental changes as well as significant advances through innovative step changes are essential if the industry is going to respond effectively to the challenges in the years to come.

Whilst progress in implementing the outcomes of the original *Alumina Technology Roadmap* were less than successful in its early years, two significant developments in the mid-2000s have contributed to a clearer path forward culminating in this current substantial update of the *Roadmap*: first, the International Aluminium Institute (IAI) established a Bauxite & Alumina Committee (BAC); and, secondly, the Alumina Technical Panel (ATP), currently comprising the R&D managers of five of the world's major alumina producers, was reinvigorated.

The objectives of the BAC are:

- Promoting the exchange of data on Priority Issues;
- Establishing key performance indicators based on the regular collection of data;
- Establishing voluntary objectives for global industry;
- Sharing best practices and set benchmarks against which industry can measure its environmental performance;
- Establishing impact of bauxite mining and alumina refining as part of the full aluminium lifecycle; and
- Developing messaging on common issues in order to harmonise industry response to stakeholder concerns.

The establishment of the BAC in 2005 was a very positive move to drive the *Roadmap* initiatives forward with renewed vigour. The BAC has a broad industry membership and, with its links directly to the Board of the IAI, has the most senior management in the alumina producers directly interested in its outcomes.

The ATP; was formed to promote and implement collaborative research and technology development in the alumina industry and to maximise technological progress within issues of common concern. The ATP serves as an advisory/project management/technical arm of the BAC.

The combination of efforts by the BAC and the ATP enhances the opportunity for more collaborative *Roadmap* projects being defined and successfully implemented.

The IAI Board has endorsed a clear working relationship between the BAC and the ATP – creating a strong information flow between the two groups, joint sessions at BAC meetings and good interaction at international meetings such as the Alumina Quality Workshops and TMS Light Metals annual meetings.

This *Alumina Technology Roadmap* focuses primarily on the application of technologies to solve the challenges facing the industry. It must also be seen in the wider context of the industry globally, with increasing focus on sustainable operations – and linked with the substantially broader efforts which the IAI brings to bear; these include:

- Regular Bauxite Mining and Bauxite Residue Industry Surveys;
- Sustainable Bauxite Mining Reports;
- Statistical Reports on Energy Used in Metallurgical Alumina Production; and
- Global Environmental Sustainability Roadmap.

2. The update process

The first step in preparing this current update of the *Alumina Technology Roadmap* was a comprehensive questionnaire to all BAC members representing the alumina producers worldwide. ATP members were instrumental in critiquing the questionnaire to ensure its appropriateness for the task; a copy of the questionnaire is provided in Appendix A.

The alumina industry's responses to the questionnaire enabled the identification of their *Vision* and *Strategic Goals*, discussed in Chapter 3, and their *Priority Areas*, detailed in Appendix B. Further to this valuable input a unique opportunity to canvass the views of the broad Chinese industry arose with the BAC holding a meeting in Zhengzhou, China on 27-28 April 2010 at the invitation of the Chinese alumina producers. During the meeting attendees were able to provide their own input on their *Priority Areas*; a summary of the ranked responses is also provided in Appendix B. It is appropriate to provide a separate summary, given the relative uniqueness of the Chinese bauxites and the relative production capacity of the Chinese alumina industry.

Whilst canvassing the thoughts of the worldwide alumina industry it was also considered appropriate to approach a range of "Suppliers" to the industry for their views on the top technical challenges facing the alumina industry and the timeframes for addressing these challenges. "Supplier" includes research institutions, engineering companies, equipment and reagent suppliers, and government agencies. Their identified *Priority Areas* are detailed in Appendix C.

Vision

The industry expects by 2030 to achieve the following goals:

- To be recognized by Society and the Community as
  - An industry with the highest standards in health, safety and the environment;
  - a valuable partner deserving community trust and ongoing licence to operate; and
  - an employer of choice for its workforce.

- To build new refineries more cheaply and faster and to operate plants at lower costs in order to keep the aluminium industry competitive.

- To manage bauxite residue in such a way that promotes/encourages use as a product and a resource for other industries and for all remaining residue to be stored in an environmentally acceptable form.

- To develop the technologies required for
  - Refineries being self sufficient in water usage, with low or no impact on local water supply;
  - minimizing discharges including water, dusts, alkali, VOCs and metals to levels which have no real or perceived impact on the surrounding environment and communities;
  - improving refinery energy efficiency and developing alternative energy sources as well as carbon capture and storage possibilities in order to reduce GHG footprint;
  - reducing the impact of scale (deposition of material on surfaces) on refinery operations for better equipment efficiency and lower costs;
  - increasing substantially liquor productivity, allowing energy savings and capital expenditure reduction;
  - achieving greater flexibility in treating a range of bauxite ores, particularly low grade; and
  - improving alumina quality for more energy efficient production of high quality aluminium metal.

Strategic Goals

The Strategic Goals identified can be linked into five key areas:

Society and the local community

- Achieve zero injuries and health impacts in the workplace;
- Achieve zero environmental incidents in operation; and
- Achieve zero impact of refinery operations on the community.

Technology

- Low grade bauxite treatment prior to or in the alumina production process to reduce transformation costs by 20% (soda savings, lower impurity input) and residue storage by 30%;
- Reduce fresh controllable water input to zero by improving water re-use and/or develop refining processes requiring substantially less water input;
- Develop extraction/dissolution of VOCs allowing their capture and oxidation to harmless, odourless compounds or develop new refinery processes with zero or substantially reduced VOC emissions;
- Reduce soda consumed in desilication by 50% whilst keeping other overall chemical costs steady;
- Achieve a 50% reduction of scale impact on performance and availability by 2020;
- Achieve 20% precipitation yield increase whilst keeping the same capital cost per production tonne; and
- Define equipment required for CO_2 capture as techniques become available.

Energy

- Reduce overall fossil fuel consumption by:
  - » increasing cogeneration and cooperation with energy producers;
  - » developing internal synergies between the boiler house and calcination; and
  - » utilising alternative energy sources.
- Reduce specific energy consumption by:
  - » increasing performances of slurry heat exchangers;
  - » increasing liquor productivity; and
  - » increasing low grade heat recovery.

Costs

- Reduce greenfield and brownfield refinery costs by 30% by improving refinery design and construction techniques;
- Reduce operating costs via:
  - » raw materials & energy savings;
  - » improved maintenance techniques and materials of construction; and
  - » improved service life of equipment (e.g. reduce caustic embrittlement).

Bauxite residue

- Develop sustainable residue storage without the need for ongoing management;
- Remediate all residue (including legacy residue) using various means including process-generated CO_2;
- Utilise 20% of residue by 2025;
- Increase portion of total footprint rehabilitated; and
- Reduce soda trapped in mud sent to residue storage.

From the information provided by the alumina producers and suppliers to the industry, we can identify those priority areas where collaborative efforts will enable the industry to achieve its long-term goals. The following comments are provided under the eight Focus Areas set out in the questionnaire.

Safety

Whilst eliminating accidents is an obvious, but challenging, target, specific short-term efforts are needed with eye protection, noise reduction and improved mechanical/ergonomic activities. Reducing heat stress and exposure to dust require more effort in the short- to medium term.

Eye protection

There is a pressing need for suitable eye protection that can be comfortably (and effectively) worn for extended periods.

Noise reduction

Noise affects the workforce and the neighbouring community. Efforts need to be increased to reduce noise as well as provide better hearing protection for workers.

Mechanical/ergonomic activities

Some nine activities, such as descaling tanks and vessels, can be mechanized. However, some operations will continue to require human intervention; these need to be better designed to reduce risks and accidents.

Heat stress

Removing the worker from hot areas must continue to be a priority.

Dust reduction

The workforce and local community must not be subject to dusty environments.

Emissions

There are clear challenges in the short term in reducing emissions of steam, digester venting, caustic mist, VOCs, dust and CO_2. Emissions of metals, including mercury, need to be addressed in the short to medium term.

Steam

No steam should be emitted from a refinery. It is seen as pollution, wasting water and energy. Alternative calcination technologies should be investigated (but this is seen as competitive).

Digester venting

Work has been done to capture vent gases; no emissions from digesters should be tolerated in the future.

Caustic mist

Whilst this should be captured, reliable measurement is a challenge.

VOCs

Substantial work has been done in studying these compounds, but much more is required in this very challenging area of very low (but active) concentrations.

Dust

The workforce and community must not be subject to dust emissions. These can arise from bauxite stockpiles, alumina transfer and loading, and at residue areas. Technologies are available for dust suppression but further work is required.

Carbon dioxide
All efforts must be applied to reducing this emission. The Bayer process operates in a caustic environment, conducive to CO_2 capture, but with concomitant soda loss.

Metals
Concern here is with heavy metals present at low concentrations, particularly mercury. More work is needed to understand their presence in the circuit and how they are emitted.

RESIDUE
This is a key area of the Bayer process where the challenges are common and collaboration should provide broad benefits to the industry. Effort is required in the short to medium term on improved residue storage, rehabilitation and utilisation as a resource. Atmospheric CO_2 may prove promising in neutralizing residue.

Storage
In situ remediation and leachate treatment are key areas for study.

Rehabilitation
Reducing the footprint and propensity for dusting are important aspects. Being able to complete a successful rehabilitation with no further need for leachate monitoring is an obvious goal.

Utilisation
This is the holy grail of bauxite residue, but the most challenging. Whether the material is used in, for example, construction, agriculture or environmental applications is contingent on regulatory approvals, community and business acceptance. Utilisation as a resource for further extraction of metals (soda, alumina, iron, valuable trace elements) will require further novel research.

RAW MATERIALS
Action in the short term is warranted on water, caustic soda and lime usage. The challenge of efficiently processing lower-grade bauxites is seen as demanding a short to medium term effort.

Water
Water is viewed as an increasingly valuable commodity, so efforts must be strengthened to decrease water usage, increase recycling and utilise lower grade water. Fresh water input should be reduced to zero.

Caustic soda
Reducing consumption hinges largely on the reactive silica input in the bauxite. Efforts should be increased to form alternative lower-soda DSPs and/or recover soda from DSP. Return of soda from residue areas is also important.

Lime
Lime usage in the Bayer process should be reduced simply because calcining limestone uses energy and emits CO_2. Lime must be used for causticisation, but in so doing alumina is lost. Alternative filter aids/filtration systems should be further studied.

Lower-grade bauxites
These are likely to be more utilised in the future as higher grade ores are exhausted. A key factor is higher silica to alumina ratio content, leading to increased soda consumption. Some bauxites suffer from high sulfur and low iron contents and various other impurities, warranting studies on bauxite treatment technologies.

Energy

Here the challenge in the short term is enhanced heat transfer, heat recovery (in all forms), improved digestion and evaporation and more efficient pumping. In the medium term, the mining, crushing, transportation and grinding of bauxite require improved energy efficiency.

Heat transfer

Energy is lost in poor heat transfer due to such factors as vessel scaling and non-optimal design. Efforts must be increased to improve heat transfer efficiencies.

Heat recovery

Recovering high and medium grade heat is already practised and/or feasible with known technologies. Recovering low grade heat is a greater technical and economic challenge. Some newer technologies need to be tested and applied including heat recovery from calciners.

Digestion

This area is contingent on the type of bauxite being processed. Indirect methods of heat injection avoid dilution effects. The efficiency of heat recovery must be improved.

Pumping

Much energy is used in pumping liquors and slurries around the Bayer circuit. More efficient pumps would provide substantial benefit in reducing energy usage, for example, gland water usage in pumps leads to process dilution requiring evaporation

Mining, crushing, transport and grinding of bauxite

These are areas directly influenced by the type and location of bauxite deposits. Hence mining methods and efficiency may be unique to a location. Crushing and grinding are areas where further work would be of value. Transport is dependent (again) on location; conveyor, slurry pipeline and trucking/shipping have to be dealt with on a case-by-case basis.

The Bayer Process

Despite using a chemical process that was invented by Bayer well over a century ago, there are still many challenges to improve the process. However, this is an area where competitive advantage can be a considerable driver with the result that collaborative efforts are restricted.

Key areas for attention in the short- to medium term are liquor productivity/yield, impurity removal, scale, process control (sensors), silo design, unit operations from other industries, trace element chemistry and alumina particle strength.

Liquor productivity/yield

Substantial in-house and collaborative, precompetitive work has been carried out in this area. Reducing the holding time in precipitation is an obvious way to increase production and reduce energy usage. But many factors come into play, such as impurity levels in liquor, caustic embrittlement at higher concentration, etc. Whilst it will be a significant challenge to identify ongoing areas for collaboration, the payoff is so great that appropriate efforts should be continued.

Impurity removal

This area is largely dependent on the nature of the bauxite ore, so is more pressing for some producers than others. A suite of removal technologies are available, but work would be useful on how to utilise the removed impurities (including oxalate).

Scale
More fundamental studies of scale formation are seen as useful collaborative efforts. Preventing scale formation and removal techniques are viewed as somewhat competitive in nature.

Process control
Better process control will always improve the efficiency of an operation, but is dependent on the correct information being fed in at increasingly frequent rates. This is where online sensors have a vital role to play. More work is required to develop these into more robust, reliable tools.

Silo design
Filling and emptying tanks, especially with alumina, can cause segregation and fines generation. Whilst a refinery may produce the 'perfect' alumina, buy the time it reaches a smelting pot its characteristics have changed for the worse. Better design of silos, feeding and extraction systems are required.

Unit operations from elsewhere
Traditionally the alumina industry has been somewhat insular in its use of technologies and has not embraced developments that have enhanced other industries. The viewing horizon should be broadened.

Trace element chemistry
A better understanding of trace element deportment in the Bayer process will enhance approaches to control their loss from the circuit. This is especially true for heavy metals including mercury.

Alumina particle strength
Collaborative work has been undertaken on better understanding how tougher aluminas are formed and how they behave in transport and at the smelter. But the story is not complete.

Refinery Construction & Integrity
Caustic embrittlement, erosion, wear and corrosion are challenging areas which would benefit from studies in the short term. This is also true for the planning of refineries and their capital cost and construction period. Improving concrete integrity in the short to medium term and reaction engineering in the medium term would provide significant benefits.

Caustic embrittlement, erosion, wear and corrosion
These factors are conveniently grouped together but require somewhat separate approaches to solutions. They all impact on refinery reliability, capital and operating costs, and energy usage.

Refinery planning and construction
There are benefits in looking at alternative/cheaper materials for constructing parts of refineries. Modular designs for each unit operation could facilitate more rapid construction.

Concrete integrity
Better concretes are required for refinery foundation and bunds.

Reaction engineering
Optimise reactor design, size, mixing efficiency and mass transfer.

Alternatives to the Bayer Process
Efforts to identify and develop alternative processes are not seen to be of sufficient importance to pursue in the short to medium term. However, it would be of benefit to carry out some activities at a low level under a longer (>20 year) timeframe for delivery.

5. THE WAY FORWARD

The industry faces significant and varied challenges over the next 20 years. Business and technical forces will drive many of the Roadmap imperatives. The way forward will depend on the industry's willingness to collaborate where appropriate. The process is not new: over the past four years a number of collaborative bauxite residue projects have been successfully completed with core funding by the IAI and additional company funds, monitored by the BAC with ATP input, and outcomes delivered to BAC members. [The industry, via individual producers or in specific groups, will also pursue other aspects via alternative mechanisms.]

As the custodian of the *Alumina Technology Roadmap*, it is proposed that the IAI establish a user-friendly *Alumina Technology Roadmap* section on its website to provide a ready focal point for reporting activities and project developments.

Overall success with the *Roadmap* will be achieved if there is success in a range of key projects which make up the *Roadmap*. A successful collaborative industry project requires a number of criteria to be established and followed, including agreement on the need/value in undertaking the project which must be well defined with a clear timetable for delivery of outcomes, the selection of an appropriate contractor with the required competency, availability of funding, management of intellectual property and adequate monitoring over the course of the project. Moving forward with the implementation of this Roadmap will now require identification of specific collaborative "Themes" based primarily on Bayer process unit operations and it is suggested the BAC should select a project from some (or all) of the first seven Focus Areas. For example:

Raw Materials
Bauxite beneficiation or water usage

Energy
Heat recovery

Residue
Treatment in storage or utilisation

Emissions
Dusts

Safety
Better eye protection

The Bayer Process
Scale (fundamental studies)

Refinery Construction & Integrity
Caustic embrittlement

In some of these cases a preliminary project may well be conducting a state-of-the art technology/literature review. This could then lead to a specific R&D project on one key aspect.

The *Roadmap* should also serve as a mechanism to inform suppliers to the alumina industry about its needs and integrate them into collaborative R&D activities in areas such as process sensors and materials of construction. There are already tangible examples of suppliers developing innovative solutions to the alumina industry's problems – a positive outcome from the original *Roadmap*.

Finally, the sharing of best practices among refiners can benefit all areas of plant operation. In many cases technologies existing in other industries may offer solutions to alumina industry problems. Examining other industries' responses to scale management, ore beneficiation, and waste heat recovery, for example, could help refiners develop their own solutions to these problems.

Sharing of best practices within the industry or application of best practices from other industries may represent the best pathway for industry needs that are considered low risk yet have potentially high payoff. It should be noted, however, that adopting a (new) technology from another industry does not necessarily ensure its success in the alumina industry.

New technologies that can lower costs, decrease energy consumption, reduce environmental impact, and improve worker health and safety will help ensure the industry's continued health and prosperity well into the 21^{st} century.

Technology Roadmap for Bauxite Residue Treatment and Utilization, The Aluminum Association, Inc., February 2000.
[www.aluminum.org/Content/NavigationMenu/TheIndustry/TechnologyResources/TechnologyArticles/bauxite.pdf]

Alumina Technology Roadmap, AMIRA International Limited, November 2001.
[www1.eere.energy.gov/industry/aluminum/pdfs/alumina.pdf]

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[www1.eere.energy.gov/industry/aluminum/pdfs/al_roadmap.pdf]

Alumina Technology Roadmap (minor update), International Aluminium Institute, March 2006.
[www.world-aluminium.org/UserFiles/File/AluminaTechnologyRoadmap%20Update%20FINAL%20May%202006.pdf]

REVISION/UPDATE OF THE ALUMINA TECHNOLOGY ROADMAP: QUESTIONNAIRE SEEKING INPUT, FEEDBACK

We can develop a Roadmap by taking two approaches: forward-casting and back-casting.

- Forward-casting or looking forward starts with the current technology situation, and examines ways to move forward and improve via well-defined incremental and/or step changes. It is a bottom-up approach where available ideas drive the outcomes. In the extreme, these ideas will deliver solutions but the ultimate direction may not be the ideal.
- Back-casting or looking backwards starts with defining a vision of where the alumina industry wants to be in a certain timeframe (typically 15-20 years). Hence it is a top-down approach and the vision is reached by developing the critical ideas.

Not surprisingly both approaches are needed to deliver the best result: to understand where the capabilities lead needs forward-casting, and the correct direction is confirmed by back-casting from the vision.

1. Potential Focus Areas for Incremental Improvements & Breakthrough Technologies

Which of the following Components do you believe need R&D efforts to achieve incremental improvements or breakthrough technologies in the production of alumina for aluminium smelting? Feel free to add new Components and Focus Areas.
Please complete this Table by adding Vor X in your chosen cells.
Indicate if you think R&D project outcomes in a Component could be commercially sensitive, i.e. a competitive area, and hence not appropriate for a collaborative effort.
If a collaborative effort is appropriate, are the outcomes required in the short-, medium- or long-term?

Focus Area	Component	Competitive?	Collaborative?		
			<5 years	5-15 years	>15 years
Raw Materials	*Bauxite: beneficiation, high silica*				
	Water				
	Caustic Soda				
	Lime				
	Additives				
	Other (please add)				
Energy	*Mining, crushing, transportation*				
	Grinding				
	Digestion				
	Pumping				
	Calcination				
	Heat recovery (low, medium, high grade)				
	Other (please add)				
Residue	*Storage*				
	Rehabilitation				
	Use				
	Process changes to enhance residue				
	Other (please add)				
Emissions	*Steam*				
	Digester venting				
	Caustic mist				
	VOCs				
	Dust (bauxite, alumina, residue)				
	Metals e.g. mercury				
	Other (please add)				
Safety	*Eyes: glasses, goggles, shields*				
	Hearing				
	Mechanical				
	Heat stress				
	Dust				
	Other (please add)				

The Bayer Process	*Productivity, yield*				
	Impurity removal				
	Scale				
	Modelling				
	Process control: sensors				
	Silo design				
	Unit operations from other industries				
	Other (please add)				
Refinery Construction & Integrity	*Caustic embrittlement*				
	Erosion, wear				
	Corrosion				
	Cost for greenfields vs brownfields				
	Other (please add)				
Alternatives to Bayer Process	*Produce alumina for Hall-Heroult Process*				
	Produce alternative feedstock for smelting e.g. Al chlo-ride				
	Direct smelting of aluminous ores				
Other (please add)					

2. The Roadmap Vision and Strategic Goals

The existing Alumina Technology Roadmap identified a series of Strategic Goals (p.3) that relate to issues such as:

- Reducing operating costs
- Achieving energy efficiency gains
- Capital costs of new plants
- Improving overall performance on environmental, health and safety grounds
- Acceptable product quality

To reach these goals a range of specific improvements over ongoing three-year timeframes were developed, covering such areas as:

- Increasing yield
- Decreasing caustic consumption
- Reducing process variability
- Reducing total energy consumption
- Recovering waste heat
- Reducing inputs (including water) and outputs (including impurities)
- Developing industrial synergies
- Developing sustainable bauxite residue storage and making substantial inroads into residue use.

What is your vision of your industry in 2030? Can you capture this in one simple sentence?

My vision is…………………………..

And what are your top five strategic goals? Please try to be quantitative i.e. an x% increase in precipitation yield within a years, a y% reduction in digestion energy usage in b years, etc. Such goals would then associate well with objectives identified in the IAI's sustainability roadmapping efforts.

Goal A…………
Goal B…………
Goal C…………
Goal D………..
Goal E…………

Sincere thanks for the time you have taken to complete this initial questionnaire.
The quality of the final Roadmap will reflect the contributions you make.

Appendix B: Priority Areas identified by Industry

A. Responses from the Alumina Industry outside of China

The questionnaire sent out to the industry identified 8 Focus Areas:

- Raw Materials,
- Energy,
- Residue,
- Emissions,
- Safety,
- The Bayer Process,
- Refinery Construction & Integrity, and
- Alternatives to the Bayer Process.

Each Focus Area included a number of key Components as detailed in Appendix D.

From the details provided in each Focus Area we can identify the most important aspects where the industry believes collaborative efforts are warranted:

Focus Area	Specific Area	Timeframe	Comments
Raw Materials	Water usage	S*	
	Caustic soda usage	S	
	Lime usage	S	
	Flocculant usage		Only fundamental studies
Energy	Bauxite mining, crushing, transportation	M	
	Grinding	M	
	Digestion	S-M	Also seen as competitive
	Pumping	S-M	
	Calcination	M	Also seen as competitive
	Heat recovery (low, medium & high grade)	S	
Residue	Storage (including in-situ remediation)	S-M	
	Rehabilitation	S	
	Utilisation	S, M & L	
Emissions	Steam, digester venting, caustic mist, VOCs, dust	S-M	
	Metals	S-M	
Safety	Eye protection	S	
	Hearing/noise reduction	S	
	Mechanical/ergonomic	S	
	Heat stress	S-M	
	Dust	S-M	
The Bayer Process	Liquor productivity, yield	S-M	Also seen as competitive
	Impurity removal	S-M	Also seen as competitive
	Scale	S-M	Only fundamental studies
	Process control (sensors)	S-M	Also seen as competitive
	Silo design	S-M	
	Unit operations from other industries	S-M	Also competitive
Refinery Construction & Integrity	Caustic embrittlement, erosion, wear, corrosion	S	
	Concrete integrity	S-M	
Alternatives to the Bayer Process			

*S: short-term, ≤5 years
M: medium-term, 5-15 years
L: long-term, ≥15 years

B. Responses from the Chinese Industry

During the April 2010 meeting in Zhengzhou attendees provided their own input to the questionnaire; a summary of the responses ranked in priority is as follows:

Focus Area	Ranking (Number of responses)
Energy savings	34
Bauxite residue treatment & utilisation	31
Technology development for low grade bauxite	24
Innovative sintering process & series process	20
Optimisation of Bayer Process	18
Product quality improvement	16
Alternative resources	15
Beneficiation technology	15
Equipment	15
Scale	9
High sulfur & iron bauxites	8
Improvement of precipitation rate	7
Mining technology	6
Removal of organics & impurities	6
Alternatives to Bayer Process	5
High efficiency of resource	5
Acid process	1

If we add the responses for 'Beneficiation technology' to those for 'Technology development for low grade bauxite', to which it is closely related, and then consider the 'High sulfur & iron bauxites' topic as being closely related to the 'Beneficiation' topic, we conclude that in overall ranking 'Bauxite quality' was the dominant theme of interest to the Chinese producers. The top three topics for the Chinese industry would then be:

1. Bauxite quality (i.e. processing low grade bauxites)
2. Energy savings
3. Residue management.

Appendix C: Priority Areas identified by Suppliers

"Supplier" to the industry includes worldwide public research institutions, engineering companies, equipment and reagent suppliers, and government agencies. They were asked to identify the top 3-5 technical challenges that they believe the alumina producers are facing, and over what timeframe they should be addressed.

Their responses are best classified within the 8 Focus Areas dealt with in the previous section:

- Raw Materials,
- Energy,
- Residue,
- Emissions,
- Safety,
- The Bayer Process,
- Refinery Construction & Integrity, and
- Alternatives to the Bayer Process.

Focus Area	Specific Area	Time-frame	Comments
Raw Materials	Processing lower-grade bauxites	S-M*	Possible beneficiation, high silica ores, and greater residue loads
	Reduce fresh water usage	S-M	
	Reduce caustic consumption	M	Recover caustic from various products
Energy	Reduce energy intensity	S-M	Focus on digestion
	Recover heat	S-M	
	Improve energy/steam production	S	
	Enhance heat transfer	S-M	Reduce equipment size
Residue	Storage (including in-situ remediation)	S-M	
	Rehabilitation	S	
	Utilisation	S, M & L	Regulatory issues to be resolved. Recover metal values
Emissions	Reduce environmental impact	M	In the widest sense
	Reduce CO_2 emissions	S	
	Reduce mercury emissions	S	
Safety	Eliminate accidents	S	
The Bayer Process	The precipitation bottleneck	S-M	Maximise yield to minimise energy usage
	Improved oxalate removal and use	M	
	Scale: Reduce formation Improve removal	S-M	Overdesign and downtime of refineries. Reduced energy efficiency/heat transfer
	Deportment of toxic trace elements in Bayer liquors	S-M	
	Formation of odours	M	
	Improved methods for organics removal	S	Lower grade bauxites will increase impurity loads
	Improved thickener and filtration operation	S	
	Process flowsheeting	S	
	Alumina particle strength	S-M	
Refinery Construction & Integrity	Planning, capital cost and construction period	S	Cheaper materials and modular design
	Caustic embrittlement	S-M	Operate at higher caustic concentrations
	Reaction engineering	M	Optimum reactor design, size, mixing & mass transfer
Alternatives to the Bayer Process	No items identified here		

*S: short-term, ≤5 years
M: medium-term, 5-15 years
L: long-term, ≥15 years

Focus Area 1: Raw Materials

- **Bauxite beneficiation, high silica bauxite**
  The majority of industry views beneficiation of bauxite and use of higher silica bauxites as competitive areas where they would prefer not to collaborate. This is despite grades generally falling in value, with increasing reactive silica. Each bauxite deposit tends to be unique in character, with other considerations (such as the organic carbon content and the form of iron minerals present) coming into play, perhaps mitigating against general approaches to beneficiation.
- **Water**
  Water is seen as an increasingly valuable commodity, and so there is keen interest in collaborative efforts in the short term (~5 years) to decrease water usage and increase recycling and/or use of lower grade water.
- **Caustic soda**
  A critical raw material that increasingly is subject to the vagaries of the chlor-alkali market. Hence there's a strong push for collaboration (~5 year timeframe) reduce consumption and increase recovery and re-use.
- **Lime**
  Calcining lime sources to produce lime for causticisation is energy-intensive with CO_2 emissions. Hence from an environmental perspective, increasing lime efficiency is viewed positively. Further, alumina is lost with lime residues; this needs to be minimized. Industry supports collaborative efforts here in the short term.
- **Additives including flocculants**
  Fundamental studies on these materials, especially flocculants, have some support. But efficient usage is viewed as a competitive area.

Focus Area 2: Energy

- **Bauxite mining, crushing & transportation**
  Viewed by the industry as appropriate areas for collaborative efforts primarily in the medium (5-15 years) timeframe.
- **Grinding**
  Similar views to previous entry.
- **Digestion**
  Some producers view this as a competitive area, others suggesting collaboration in the short to medium term timeframe. Views may relate to bauxite sources and hence need for higher temperature digestion, with tube digesters providing advantages.
- **Pumping**
  Clearly an area for collaboration in the short to medium term. Increased pumping efficiency, reduced energy usage and better reliability are key aspects.
- **Calcination**
  The majority of producers view this are as competitive, but a third suggest collaborative efforts in the medium term. Suppliers to the industry now dominate this area.
- **Heat recovery (low, medium & high grade)**
  Another area ripe for collaboration in the shorter term. Recovering heat and hence reducing energy is a critical aspect in current circumstances. There are particular challenges in recovering and utilizing low-grade heat.
- **Improved cogeneration**
  A potential area for collaboration in the shorter term.
- **Greenhouse accounting**
  As for previous entry.

Focus Area 3: Residue

- **Storage**
  Overall support for collaboration in the short to medium term. Some support for in-situ remediation and Leachate treatment.
- **Rehabilitation**
  As for previous comment, with emphasis on shorter term.
- **Use**
  Overall support for collaboration, but evenly split between short-, medium- and long-term efforts. One producer felt this is a competitive area. However, most usage (of larger quantities) will happen closer to source. One important aspect to research and resolve is achieving appropriate regulatory frameworks for use of an industrial residue.
- **Process changes to enhance residue value**
  Somewhat similar response to previous entry, with two producers indicating a competitive aspect.
- **Recovery of alumina**
  Not a great deal of interest.

Focus Area 4: Emissions

- **Steam**
  This includes visible plumes form calcination. Broad support for collaborative efforts in the shorter term. Capture of steam in calcination may lead to heat recovery but also different calcining technologies, which could provide competitive advantage.
- **Digester venting**
  Again, broad support for collaboration in the near term.
- **Caustic mist**
  As for previous comment. Reliable measurement of caustic mist is a challenge.
- **Volatile organic compounds**
  Again, broad support for collaboration in the near term.
- **Dust**
  This includes bauxite, alumina and residue dusts. Strong support for collaboration in the short term.
- **Metals**
  This includes mercury and other heavy metals. Strong support over the short to medium term.
- **Contaminated water**
  Such as condensate. Minor support. Recovering water will assume increasing importance in the future.
- **Stormwater management**
  As for previous comment.
- **Carbon capture**
  From, for example flue gases. Some interest.
- **Emissions modelling**
  Some interest in the medium term.
- **Noise**
  Some interest in reduction and modelling in the medium term
- **Light spill**
  Seen as a medium term issue.
- **Radionuclides**
  Some interest in the short- to medium term. Potential issues may be in downstream use of residue offsite.
- **Spills & containment**
  Some interest in short- to medium term. Reducing any wastages is increasingly important.

Focus Area 5: Safety

- **Eyes**
  Use of glasses, goggles and shields. Strong support for collaboration in the near term, to produce improved eye protection.
- **Hearing**
  Broad support in the near term.
- **Mechanical/ergonomic**
  As for previous comment.
- **Heat stress**
  Broad support across the short to medium timeframe.
- **Dust**
  Strong support across the short to medium timeframe.
- **Equipment isolation**
  This relates to tagout and lockout procedures. Some support in the short term.

Focus Area 6: The Bayer Process

- **Productivity, yield**
  An even split between producers who see this as a competitive area and those who see benefits of collaboration over the short to medium term.
- **Impurity removal**
  Same comment as for previous entry.
- **Scale**
  Same comment as for previous entry. Fundamentals of scale formation and growth are seen to be worthy of collaborative studies, but scale prevention and removal are seen as competitive areas.
- **Modelling**
  Broader view that this is a competitive area, with minor view that collaboration in the medium term would be beneficial.

- **Process control (sensors)**
  Similar comment as for Impurity Removal.
- **Silo design**
  Collaboration in the near to medium term is seen as producing beneficial outcomes.
- **Unit operations from other industries**
  Similar comment to previous entry. One producer sees this as a competitive advantage.
- **Fundamental chemistry**
  This relates to areas such as trace element deportment and speciation. A minor interest in collaboration in the medium term.

Focus Area 7: Refinery Construction & Integrity

- **Caustic embrittlement**
  Including stress corrosion cracking. Overall interest in collaborative efforts, mainly in the short term.
- **Erosion, wear**
  This includes CFD modelling. Similar comment to previous entry.
- **Corrosion**
  Similar comment to previous entry.
- **Cost for greenfields vs brownfields**
  Seen by the majority of producers as a competitive area.
- **Concrete integrity**
  Some interest in collaborating in the short- to medium term.

Focus Area 8: Alternatives to the Bayer Process

- **Produce alumina for Hall-Heroult Process**
  More producers see this as a competitive area compared to fewer who see benefits of collaborating in the longer term.
- **Produce alternative feedstocks for smelting**
  As for previous comment.
- **Direct smelting of aluminous ores**
  As for previous comment.

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