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THE ALUMINA TECHNOLOGY ROADMAP

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Abstract

In an unprecedented global collaboration, more than 30 international leaders in the alumina refining industry have reached a consensus on the research and development activities needed to address the industry's technical challenges over the next 20 years. The result of this effort is the *Alumina Technology Roadmap*, a strategic plan containing a goal-based R&D agenda that can be pursued by both individual companies and collaborative partnerships between companies, government, academia, and other members of the research community. The framework for developing the roadmap was a set of explicit targets for reducing capital and operating costs; improving energy efficiency; enhancing environmental performance, safety, and health; and meeting customer needs. The roadmap was coordinated by AMIRA International, the mineral industry research association, and supported by the U.S. Department of Energy, the Australian Department of Industry, Science, and Resources, The Aluminum Association, Inc., the Australian Aluminium Council, and the Government of Western Australia. An alumina technology committee has been established to serve as a focal point for implementation of the roadmap.

The Technology Roadmap Concept

A technology roadmap is a strategic plan that includes a goal-based research and development agenda that can be pursued by both individual companies and collaborative partnerships between companies, research organizations, and government agencies. The technology roadmap represents a major component of the "Industry of the Future" strategy embraced by the U.S. Department of Energy, Office of Industrial Technologies (DOE/OIT) for a number of energy-intensive industries. Under this strategy, the industry develops a vision for its future and a technology roadmap to achieve that vision.

In 1996, the U.S. aluminum industry and the DOE/OIT agreed to collaborate on industry-led, government-supported, pre-competitive R&D to increase energy efficiency and reduce wastes in the production of aluminium. The partnership has been so successful that following the development of an industry vision – *Partnerships for the Future* – not one but a series of five technology roadmaps has been developed. In addition to a generic technology roadmap, the aluminum industry has developed roadmaps related to inert anodes and advanced smelter technology, the use of aluminum in automotive markets, the handling and treatment of bauxite residue, and the use of advanced ceramics to improve aluminum production and processing. These roadmaps have been distributed globally and have helped spawn similar strategic planning activities around the world. The *Alumina Technology Roadmap* represents the last significant portion of the production chain to be addressed.

Development of the Alumina Technology Roadmap

The *Alumina Technology Roadmap* represents a unique global partnership involving the collaborative efforts of industry groups from the major international companies operating on four continents, government representatives from both the United States and Australia, and representatives from the academic community and industry associations. All were drawn together under the auspices of AMIRA International, the mineral industry research association, to consider and develop technology plans for the alumina industry through the year 2020. Given the globalization of the aluminium industry, and the fact that Australia is by far the largest producer and exporter of alumina, it is most appropriate that the input for the roadmap was developed at a workshop in Fremantle, Western Australia in May 2001.

A steering committee of international technology experts guided the development of the roadmap. An essential first step was the establishment of critical technology goals to which the industry should aspire. These ambitious goals (see Table I) establish the long-term vision and encompass the challenges for alumina as a commodity – energy efficiency, environmental performance, safety, sustainability, and customer expectations – as well as the product challenges of quality, consistency, and performance.

Table I: Alumina Technology Roadmap Strategic Goals

The Commodity Challenge
Through the application of technology, • Reduce operating costs of existing plants by 3% per annum • Achieve substantial energy efficiency gains against a benchmark of reducing total energy consumption to 25% below current bauxite specific best practice • Target capital costs of new plants at <US\$500/annual tonne and falling, with major expansion at half this cost, achieved within a framework of return on investment before tax of greater than 18% • Contribute to improvement of overall performance on environment, health, and safety to world's best practice and consistent with global sustainable development principles • Produce a product that meets all of our customers' current and future needs
This indicates a need to improve over a 5 to 20 year period through • Increasing yield by 20% above current bauxite specific best practice • Reducing desilication product caustic consumption to 30 kg/tonne Al_2O_3 and reducing other losses (excluding losses to product) to best practice • Achieving a simple capable process by significantly reducing process variability (3 sigma of <5%) through elimination of the effects of scaling and blockages, by more reliable equipment, better materials, process automation, and advanced control • Reducing total energy consumption through improved methods of calcination, cogeneration, and process improvements • Developing and applying combustion and power generation technology from which waste heat sources can be used for production of alumina, capable of operating at a power generation to alumina ratio that is not significantly less than that for the benchmark of best present technology operated on a natural gas, unaffected by bauxite digestion temperature or energy source, other than its net calorific value • Developing capable processes to achieve a significant reduction and recycling of all other inputs and outputs including water, odours, VOCs, mercury, oxalates, etc. • Focusing on opportunities with synergistic industries such as caustic soda and power generation • Developing methods to achieve a 1,000-year ecologically sustainable storage of red mud and other solid wastes in existing storages, and make substantial progress in storage for later reuse as well as achieve substantial progress in the reuse of the red mud
The Product Challenge
• Improving consistency of alumina with 3 sigma limits of less than half of the present levels, with emphasis on dust, particle toughness after dry scrubbing, and impurities including sodium and silica • Developing, in conjunction with the aluminium industry, sufficiently good delivery systems such that adequate dispersion is obtained at the cell, thus allowing the alumima to readily dissolve in conventional and modified reduction cells in the temperature range 840-900C and potentially as low as 750C

The goals reflect the industry's acknowledgment of the growing impact of environmental and social issues on business practices.

The resulting roadmap outlines a comprehensive long-term research and development plan that defines the industry's collective future and establishes a clear pathway forward. It emphasizes twelve high-priority R&D areas deemed most significant in addressing the strategic goals. Both continuous improvement through incremental changes as well as significant advances through innovative step changes will be essential if the industry is going to respond effectively to the challenges in the years to come.

Expected Benefits of the Roadmap

Continued growth of the alumina refining industry will occur in a setting of changing competitive pressures and growing public expectations for clean and sustainable industry. Companies that acknowledge the growing impact of environmental and social issues on business will be more competitive in the long term.

The expected benefits of using the technology roadmap include increasing governments' capacity to build strategic research alliances and enabling industry to capitalize on emerging economic opportunities through early and improved access to leading-edge technology. It is anticipated that the development of this roadmap will serve to complement other ongoing efforts to enhance the understanding of the industry by governments and other stakeholders, such as the national laboratories and universities.

The Australian industry and Government are currently putting in place a long-term vision for the industry in Australia, under the title of the Light Metals Action Agenda. The technology roadmap approach has been embraced as a key component of this strategy. The development of the Alumina Technology

Roadmap has also been a major action item under the Australian Government's Energy Efficiency Best Practice program.

Roadmap Themes

Six major themes encompass the highest-priority research and development needs identified by the industry (see Table II).

Table II: Major Alumina Technology Roadmap Themes

Themes
Bayer process chemistry and alternatives
Resource utilization
Energy efficiency
Process and knowledge management
Residue treatment and reuse
Safety/human exposure

Changes in Bayer process chemistry can improve refinery productivity and yield, which in turn impact cost and energy efficiency. Major topics include:

- Acceleration of precipitation rates
- Desilication product (DSP) chemistry
- Scale formation
- Removal and recovery of impurities from the Bayer circuit
- Understanding and reducing the variations in alumina quality and consistency.

The development of alternatives to the Bayer process (i.e., direct reduction of alumina or a non-caustic route) must be considered as potential long-term solutions to eliminating problems associated with the Bayer process. Step change approaches are also indicated in changing the process chemistry to eliminate scale.

Resource utilization issues center on bauxite modification or beneficiation and caustic soda consumption. The industry must take further steps to develop technologies and strategies to effectively manage its resources for the future. The capability to use lower quality input materials – including lower grades of bauxite, caustic, and lime – is a key part of this strategy.

Maximizing the use of bauxite reserves is particularly important to the future of the industry; the supply of economical gibbsitic ore is not as large as ores requiring more vigorous treatment. Improvements in resource utilization create benefits that ripple through to plant efficiency and environmental performance. By maximizing the alumina extracted per ton of bauxite, refiners reduce the input of impurities per ton of alumina and also the quantity of residue generated.

The energy efficiency of the Bayer process can be improved directly or indirectly through the use of cogeneration, waste heat utilization, and synergies with nearby industries, as well as through equipment advances or process changes. Reducing residence time in the Bayer process equipment also reduces energy consumption, losses, and capital costs while increasing productivity. Improving the thermal efficiency of refinery operations also reduces emissions of greenhouse gases.

The alumina industry is not as advanced as the chemical and some other industries in its use of process management techniques, particularly models and control systems. Increased use of Bayer-specific models and automation could reduce process variation while reducing human exposure to the caustic environment.

Knowledge management systems are also critically lacking in the industry, leading to repeated mistakes, particularly at the operations level. Benchmarking is a mechanism by which individual refineries can gauge their performance and practices against each other, and the industry can measure itself against other industries.

The alumina industry has been investigating options for residue treatment and utilization for years with limited success. The economics of using the residue in most applications are not currently favorable. Inventories of this byproduct represent a liability for the industry that extends well into the future, and technology is needed to find economically viable alternative uses.

Reducing human exposure to safety risks can be accomplished through many of the topics already discussed, including reducing scale and increasing plant automation. The push for full automation is a common goal throughout the industry and would promote the awareness of refineries as well run, modern, and safe. Industry-wide standards and criteria for safety in plant design and operation, as well as standardized training, would help establish a culture of operating safety within the refining industry.

The twelve highest priority technology needs identified by the industry participants are shown in Table III. This table summarizes the key elements of the R&D response to these needs, the technical and economic risk of developing the technology, and the potential payoff if successful. The table also shows the potential impacts of the successful technology on the industry goals of operating cost; capital cost; energy consumption; environment, safety, and health; and product quality.

The other technical needs identified by the industry have been organized into thirteen areas, some of which are related to the high-priority needs but were sufficiently unique to warrant separate mention. The thirteen areas include the major process steps of digestion, clarification, precipitation, and calcination as well as the following topics:

- New process chemistries and alternative raw materials
- Product characteristics and quality
- Controls and instrumentation
- Models and tools/process management
- Knowledge management
- Energy and fuels
- Bauxite residue
- Refinery releases
- Minimization of human exposure and improved safety.

Table III: Highest Priority R&D Needs for the Alumina Refining Industry

Technology Need	R&D Response	Potential Payoff	Technical/ Economic Risk	Impacts
Alternative Methods to Accelerate Precipitation Rates	Investigate alternative methods (both chemical and physical) to accelerate precipitation rates while maintaining product quality. Develop a full understanding of the precipitation mechanism. Develop cost-effective catalysts.	High	High	• Increased yield is equivalent to lower unit energy requirements. • Fewer precipitators mean lower capital cost per ton of alumina for brownfield and greenfield projects. • May be a challenge to maintain product quality.
Conversion of Monohydrate Bauxite to a More Beneficial State	Estimate direct and spin-off benefits of converting monohydrate to trihydrate or some intermediate state. Identify intermediaries and investigate thermally efficient process options for conversion.	Moderate	Moderate	• Energy savings associated with moving to low-temperature digestion. • Eliminates need for causticization, oxalate destruction, sweetening, and seed wash; fewer heaters required. • Improved alumina properties with fewer impurities.
Cost-Effective Inerting and Alternative Uses of Bauxite Residue	Conduct expert brainstorming session or workshop to scope out potential solutions. Investigate inerting options. Coordinate with other sectors and industries on potential uses of residue.	Moderate to High	High	• Capital cost savings associated with reduced residue storage requirements. • Large reduction in residue stockpiles and improved sustainability and environmental responsibility.
Direct Reduction of Bauxite or Other Aluminium Materials	Examine the limits of the process and establish a baseline of fundamental data. Identify and evaluate reduction process options. Determine the material requirements of the reaction vessel.	High	High	• Substantial reduction in energy requirements of producing aluminium. • Elimination of Bayer process equipment and caustic. • Reduced manpower requirements. • Unknown impact on environment, safety, and product quality.
Full Automation and Improved Control Strategies	Benchmark the status of the alumina refining industry versus other industries. Develop more reliable sensors and instrumentation capable of surviving in caustic environments. Develop predictive models for the Bayer process.	Moderate	Moderate	• Incremental improvements in productivity and energy efficiency. • Reduced manpower requirements. • Reduced human interaction in potentially dangerous environments. • Better product quality/consistency.
Impurity Removal from Bauxite and the Beneficiation of Bauxite	Develop a better understanding of bauxite and estimate future requirements. Develop methods to modify bauxite in order to increase the percentage of extractable alumina. Explore chemical and biological means for removing impurities from bauxite.	High	Moderate	• Increased liquor productivity (lower caustic consumption). • Increased refinery output and a lower capital cost per ton of alumina. • Maximized use of bauxite reserves. • Less degradation of alumina quality.
Impurity Removal from Bayer Liquor	Develop a better understanding of various organics and determine their relative impact. Examine various options for removing impurities, including techniques to specifically attack the worst offenders.	Moderate to High	Moderate	• Increased liquor productivity (lower caustic consumption). • Increased refinery output and a lower capital cost per ton of alumina. • Maximized use of bauxite reserves. • Less degradation of alumina quality.

Technology Need	R&D Response	Potential Payoff	Technical/ Economic Risk	Impacts
Knowledge Management and Best Practices Benchmarking	Benchmark operating practices in the alumina industry versus other industries (e.g., chemicals and petrochemicals, power). Develop information management tools and knowledge management techniques. Establish industry-wide cooperative standards and criteria for engineering design.	Moderate to High	Low	Create the potential for: • More efficient operation • Reduced manpower requirements and reduced human exposure for descaling • Lower maintenance costs • Improved product quality through better process control and predictive modeling
Major Reduction in Caustic Consumption	Benchmark current caustic consumption in terms of locations and quantity. Develop methods to alter the chemistry of bauxite so that less caustic is required. Develop a better understanding of DSP and investigate ways to alter its chemistry so that less caustic is lost.	High	Moderate to High	• Large cost savings from reduced caustic requirements. • Reduced handling of a dangerous substance and less likelihood of spills.
Scale Management	Perform scoping study of scale issues, including industry benchmark comparison. Conduct fundamental research to eliminate scale and prevent scale initiation and formation. Investigate chemical, biological, mechanical, and material solutions as well as new process designs.	High	Moderate to High	• Large reduction in maintenance requirements. • Improved productivity. • Energy savings from higher transfer efficiency in the heat exchangers. • Lower capital costs from reduced requirements for heaters. • Reduced human interaction in descaling.
Technical Solutions for Refinery Releases	Conduct scoping study to determine possible next steps. Investigate technical options and share industry best practices. Develop non-end-of-pipe removal of trace metals. Develop better instrumentation and standardize design practices to minimize spills. Model full mass balance to track all constituents.	Moderate to High	High	• Reduction in air pollutant emissions, spills, and groundwater contamination. • Ability to provide "green" alumina to customers. • Small reduction in caustic consumption.
Waste Heat Recovery	Recover and use the waste in the Bayer circuit. Utilize waste heat from nearby power plants or other primary energy users. Examine existing technologies in energy storage or conversion that are applicable to refineries.	Moderate	Low	• Capital cost savings from reduced requirement for boilers (if recover outside waste heat). • Moderate to high energy savings.

Roadmap Implementation

Through the technology road-mapping process, the alumina refining industry has acknowledged the importance of strategic research and development and innovation for a sustainable future. The industry now faces the challenge of backing its commitments with ongoing, concrete actions.

As part of its strategy for implementing the roadmap, the industry has formed the Alumina Technology Committee, consisting of representatives from major refining companies and industry associations. The committee will:

- Advance initiatives from the roadmap
- Identify appropriate subgroups to sponsor research projects and other initiatives and monitor their progress
- Establish and maintain an ongoing review of the long-term goals of technology development for the alumina industry and benchmark technical progress towards those goals
- Monitor and enhance the alumina research infrastructure to facilitate delivery of leading-edge, pre-competitive research and suitably trained personnel for the industry
- Inform key decision makers within companies and governments to ensure adequate understanding of the priorities in alumina technology development and commitment to necessary research funding
- Engender a long-term perspective for research needs and delivered outcomes
- Leverage industry research funds with successful applications to relevant government funding programs
- Provide a concerted technical focus for dealings with suppliers (chemical, equipment, engineering) to the industry

- Act in a referral role in dealings with the industry associations on technical issues
- Provide an appropriate framework for discussion of the future technology goals of the alumina industry and wide dissemination of information.

Implementing the research activities in this roadmap will require a substantial effort on the part of the alumina industry to increase corporate spending on R&D, handle complex intellectual property issues, and overcome other difficulties and costs involved in developing and demonstrating new technology. Historically, companies have been reluctant to embrace the outcome of R&D because of the perceived risk and the push for a quick payback on investments.

The alumina industry should make every effort to move forward with the research priorities in the roadmap so that it can begin to reap the benefits. 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 21st century.

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