



# Alumina Technology Roadmap



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# Table of Contents

Preface .....	i
Chapter 1 Introduction .....	1
Chapter 2 Alumina Industry Research and Technology Needs .....	3
Chapter 3 Implementing the Roadmap Initiatives .....	7
Chapter 4 Moving Forward .....	11
Bibliography .....	13
Appendix A Priority R&D Needs .....	15
Appendix B R&D Areas .....	29
Appendix C The IAI Bauxite & Alumina Committee .....	43
Appendix D List of Acronyms .....	45





# Preface

The first edition of this *Alumina Technology Roadmap* was published in November 2001, following an industry-wide workshop held in May that year and 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 then nine alumina companies directly involved.

Prior to 2001 the DOE/OIT had been instrumental in developments assisting the aluminium industry, following the industry's production of a vision for its future and technology roadmaps to achieve that vision. In addition to a generic roadmap, the industry developed roadmaps related to inert anodes and advanced smelter technology, the use of aluminium in automotive markets, the handling and treatment of bauxite residue, and the use of advanced ceramics to improve aluminium production and processing. The 2001 alumina roadmap represented the last significant portion of the production chain to be addressed.

Roadmaps should be living documents that periodically need updating as technology developments change industry sectors in different ways. Hence the Aluminum Association re-issued an updated Aluminum Industry Technology Roadmap in February 2003, following publication of the original Roadmap in 1997.

Experience over the past four years in implementing the outcomes of the original Alumina Technology Roadmap clearly points to the need to review its contents and produce an update. This will ensure the document does communicate the future needs of the industry, focus the efforts of diverse groups such as public research laboratories, supplier companies and the universities on critical issues, and align the interests of all stakeholders.





# 1 Introduction

The alumina industry continues to face similar issues as most other global commodity producers: social and environmental reporting, the challenge of sustainable operations, the image of a ‘green’ industry, and competition from substitute materials. Individually each producer is addressing these challenges. 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 the industry-wide goals.

In producing the original *Alumina Technology Roadmap* the essential first step was the development of critical technology goals to which the industry should aspire. These ambitious goals establish the long-term vision and encompass the challenges for alumina as a commodity — energy efficiency, safety, environmental performance, sustainability issues, and customer expectations — as well as the product challenges of quality, consistency, and performance. The goals reflect the industry’s acknowledgment of the growing impact of environmental and social issues on business practices. Improving overall performance on environment, health, and safety, for example, will push the industry beyond current best practice and enhance its long-term competitiveness. The specific industry strategic goals for the year 2020 in the original *Roadmap* are shown in Exhibit 1.

These strategic goals are just as valid today as they were four years ago.

The initial *Roadmap* outlined a comprehensive long-term research and development plan that defined the industry’s collective future and established a clear pathway forward. It emphasized twelve high-priority R&D needs (refer to Appendix A) deemed most significant in addressing the strategic 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.

## Exhibit 1. 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, with 3 year intermediate goals, through

- ◆ Increasing yield by 20% above current bauxite specific best practice
- ◆ Reducing DSP caustic consumption to 30 kg/tonne Al<sub>2</sub>O<sub>3</sub> and reducing other losses (excluding 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 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.
- ◆ Focussing 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 alumina to readily dissolve in conventional and modified reduction cells in the temperature range 840-900C and potentially as low as 750C.



## 2 Alumina Industry Research and Technology Needs

The original roadmap identified six major themes encompassing the highest-priority research and development needs identified by the industry, as shown in Exhibit 2. These themes were:

- Bayer process chemistry and alternatives,
- resource utilization,
- energy efficiency,
- process and knowledge management,
- residue treatment and reuse, and
- safety/human exposure.

Appendix A highlights the twelve priority R&D needs for the alumina refining industry. The details shown include:

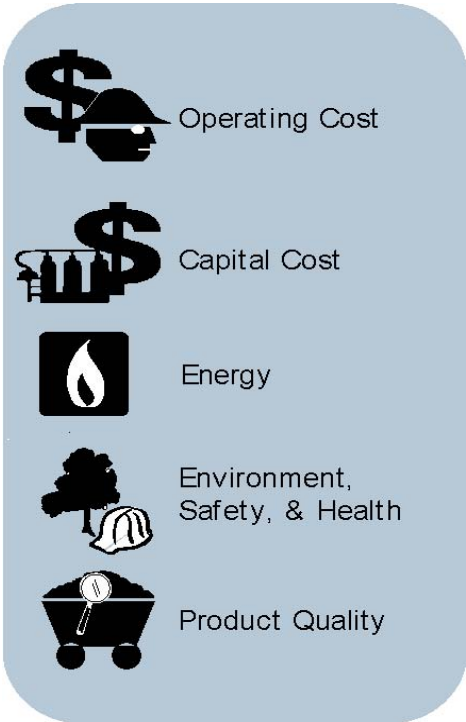
- the likely partners to be involved in each research effort
- the technical and economic risk of developing the technology and the potential payoff if successful
- the time frame for usable results to be developed, given that research could begin almost immediately with no funding constraints

- the key challenges that the R&D activity would address
- a list of some of the technical elements that should be considered during project scoping
- the potential impacts of the successful technology on the five main industry goals—operating cost; capital cost; energy consumption; environment, safety, and health; and product quality.






Following the highest priority needs is a discussion of thirteen R&D areas (Appendix B) that encompass all of the additional research needs identified by the industry. Some of the items are related to those in the priority R&D list but are sufficiently unique to warrant separate mention. As with the priority R&D needs, the key challenges for each R&D area are noted. The individual research needs are organized by the time frame in which results could reasonably be anticipated: near term (1 to 3 years), mid term (3 to 7 years), and long term (>7 years).

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# Strategic Goal Legend



A legend box with a light blue background and rounded corners. It contains five entries, each with an icon and a text label:

-  Operating Cost
-  Capital Cost
-  Energy
-  Environment, Safety, & Health
-  Product Quality

## Exhibit 2. Relationship Between Priority R&D Needs and Major Roadmap Themes

Priority R&D Need	Major Themes					
	Bayer Process Chemistry and Alternatives	Resource Utilization	Energy Efficiency	Process and Knowledge Management	Residue Treatment and Reuse	Safety/Human Exposure
Alternative Methods to Accelerate Precipitation Rates	✓		✓			
Bauxite Residue: Cost-Effective Inerting and Alternative Uses		✓			✓	
Conversion of Monohydrate Bauxite to a More Beneficial State	✓	✓	✓			
Direct Reduction of Bauxite or Other Aluminium Materials	✓	✓	✓			
Full Automation/Improved Control Strategies				✓		✓
Impurity Removal: Bauxite and Bauxite Beneficiation	✓	✓	✓			
Impurity Removal: Bayer Liquor	✓					
Knowledge Management and Best Practices Benchmarking				✓		
Major Reduction in Caustic Consumption	✓	✓				✓
Scale Management	✓	✓	✓			✓
Technical Solutions for Refinery Releases						✓
Waste Heat Recovery		✓	✓			





# 3 Implementing the Roadmap Initiatives

To progress implementation of the *Alumina Technology Roadmap* outcomes the industry established an Alumina Roadmap Committee (ARC). The ARC was comprised of key industry representatives, all at the upper technical management echelons of their companies.

The **Terms of Reference** for the ARC were to:

- Advance initiatives from the Technology 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.
- Monitor & 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.

The **Activities** of the ARC were as follows:

- The Committee meets on average twice a year, via face-to-face, teleconference or videoconference means. These meetings should, where possible, be organised around a major industry meeting, such as the Annual TMS meeting and the Alumina Quality Workshop.
- The chairmanship of the Committee should be decided by the members on an annual basis.
- Relevant government representatives will be kept informed of the Committee's business by receiving minutes of the meetings.
- Research providers and consultants will be involved by invitation to consider specific topics at meetings.
- The Committee may commission reviews on specific topics from time to time.
- The wider industry meetings (TMS, AQW, etc.) should be used as a vehicle for the information and review process.

- 
- AMIRA International will act as the secretariat in the planning, facilitation and reporting of meetings.

The ARC has put considerable effort into ranking the Priority R&D Needs in order to initiate specific collaborative research projects that would engage a broad range of industry companies. The first step was to seek feedback on the 12 Areas and then summarise as High Importance vs. Low Importance. Exhibit 3 provides an overview of the responses. The top six topics were then taken and templates developed to define the problem.

These six areas were:

- Scale Management
- A Quantum Leap in Precipitation Yield while meeting Future Product Quality
- Reduce the Potential for Environmental Impacts from Bauxite Residue Storage
- Impurity Removal – Bauxite Beneficiation
- Impurity Removal – Bayer Liquor
- Refinery Releases to Air.

Further detailed discussion across the industry focussed attention on three key areas to actively develop collaborative projects:

- Alumina dusting in smelters and alumina transportation (flowability, segregation, breakdown)
- Bauxite residue
- Air emissions.

Subsequently Worley Engineering (Daniel Thomas) was contracted to develop detailed scopes for these collaborative projects. The industry agreed at a Workshop in April 2003 to pursue the Air Emissions topic via an Australian Industry Air Emissions Forum under the aegis of the Australian Aluminium Council.

The Alumina Dusting topic progressed to AMIRA Project P791 as a six-month Scoping Study which concluded in October 2004. The Alumina Transportation topic is in abeyance.

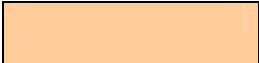
The Bauxite Residue topic was further developed into a series of discrete projects: four Foundation projects, to be supported by all companies involved in the Roadmap implementation, and a series of optional projects to follow, building on the key information developed in the Foundation projects. Exhibit 4 describes the suite of Residue projects in more detail. All four Foundation projects are currently underway and will conclude during 2006.

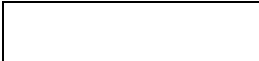
### Exhibit 3. Ranking of Twelve Priority R&D Needs

Priority	<b>1 - ALMOST ALL SAW AS IMPORTANT</b>	
3	1.1	Scale Management
2	1.2	Technical solutions for refinery releases
1	2.5-3.1	Impurity Removal
	<b>2 – HIGH BY SOME &amp; LOW BY OTHERS</b>	
4	2.1	Alternative method to accelerate precipitation rates
5	2.2	Bauxite Residue – cost effective inerting and alternate uses
	2.3	Conversion of monohydrate bauxite to a more beneficial state
	2.4	Major reduction in caustic consumption
	2.5	Impurity removal – Bauxite & Bauxite beneficiation
	<b>3 - SOME INTEREST</b>	
	3.1	Impurity Removal: Bayer Liquor
	3.2	Knowledge management & Best Practice Benchmarking
	3.3	Waste Heat recovery
	<b>4 – “LITTLE” INTEREST</b>	
	4.1	Full Automation/Improved Control Strategies
	4.2	Direct Reduction of Bauxite and Other Al materials

#### Exhibit 4. Summary of Bauxite Residue Projects

Project Number	AMIRA No.	Project Title	Research Provider
1.1	P772	Measure of Sustainability Improvement	CSRP
2.1	P942	Fundamental properties of Residue – Radionuclides	ANSTO
2.2	P928	Fundamental properties of Residue – Leachability	Alcoa and ECN (Netherlands)
2.3	P943	Fundamental properties of Residue – Ecotoxicity	CSIRO
3.1		Residue Treatment – Reactivity of Solid Alkalinity	
3.2		Residue Treatment – Long-Term Stability of Treated Residue	
3.3		Residue Treatment – In-situ Treatment	
4.1		Re-use of Residue – Targeted Research	
4.2		Re-use of Residue – Icon Projects	
4.3		Re-use of Residue – Risk Assessment Framework	
5.1		Value Extraction from Residue	

 Indicates Foundation project (sponsored by all companies currently involved, namely Alcan, Alcoa, Aughinish/Glencore, BHP Billiton, Comalco and Hydro Aluminium)

 Indicates optional project yet to be scoped



## 4 Moving Forward

The Alumina Technology Roadmap was intended to be a dynamic document. The industry faces significant and varied challenges over the next 20 years. During this period some challenges may diminish in importance while others – particularly social and environmental issues – may become more prominent. By aggressively pursuing innovative solutions to its long-term problems, the alumina industry can favorably position itself to meet these challenges as they arise.

A major objective of the original roadmap was to help alumina companies align their pre-competitive research programs with the needs of the global alumina industry. The hope was that the research agenda described in that roadmap could be pursued by both individual companies and collaborative partnerships within the industry, as well as help guide government participation. Individual companies could develop a better understanding of how their own strategic plans mesh with the priorities of the industry as a whole. The roadmap should also serve as a mechanism to better educate 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.

However, it is fair to say that developing collaborative research projects out of the roadmap has been a challenging and somewhat frustrating

exercise. It took longer than expected for the industry to agree on appropriate research topics. Scoping individual topics was a slow process. Other factors that came into play were the challenges of driving a collaborative model in a competitive industry, poor definition of the role of the ARC and communication within companies, and maintaining consistent membership of the ARC during a time when the industry underwent major rationalisations.

Two significant developments have recently prompted a desire by the industry to revisit and revise the roadmap such that it receives a greater impetus to move forward. First, the International Aluminium Institute (IAI) has constituted a Bauxite & Alumina Committee, and secondly the Alumina Technical Panel, comprised of the R&D Managers of the five major alumina producers in Australia, has undergone a new lease of life.

The International Aluminium Institute established a Bauxite & Alumina Task Group in mid-2004. As constituted, it dealt with four Priority Issues:

- Residue management
- Energy consumption
- Environment at smelters (dusting)
- Refinery emissions (gas, liquid and particulates).

Its Goals were defined as:

- 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.

At the IAI meeting in San Francisco in February 2005 it was agreed that this Task Group be combined with the Alumina Roadmap Committee to form the Bauxite & Alumina Committee under the aegis of the IAI. Paul Potter (BHP Billiton) was nominated as the BAC chairman, having been chair of both the ARC and the Task Group.

The establishment of this Bauxite & Alumina Committee is a very positive move to drive the roadmap initiatives forward with renewed vigour. The BAC has a much wider membership than the ARC had, and, with its links directly to the Board of the IAI, has the most senior personnel in the alumina producers directly interested in its outcomes.

The Alumina Technical Panel (ATP) has been in existence for more than ten years; recently it reinvigorated its efforts and now meets on a quarterly basis. It has an important role in being much more hands on with project development, implementation and monitoring than the ARC (and now the BAC) can and should ever have. Hence the appropriate combination of efforts by the BAC and the ATP should deliver a more successful outcome for collaborative projects out of the roadmap being defined and implemented.

To this end the IAI Board at its meeting in London in November 2005 endorsed a clear working relationship between the BAC and the ATP.

The ATP has recently put significant effort into defining a suite of focus areas for collaborative projects:

- Generic course on Bayer process technology
- Mechanism of gibbsite/boehmite scale formation on steel
- Scale formation – dependent on many variables (generic/follow up projects)
- Scale removal
- Microwave comminution
- Alkali mist emissions

- Red mud dust control and/or management (dust suppression/prevention)
- In process measurement tools
- Catalytic dust filter for baghouse
- Waste heat utilisation (recovery of low grade heat)
- Cyclone classification
- New materials of construction for alumina refineries.

This should serve as a very useful starting point for scoping appropriate projects.

The alumina industry can greatly improve the efficiency of its research efforts by sharing the costs of mechanisms already in place. Individual companies can benefit by sharing research results, thereby increasing the industry's collective knowledge and avoiding duplication of efforts.

Similarly, the sharing of best practices among refiners can benefit all areas of plant operation as well as environment, health, and safety aspects. 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 successfully applying a new technology in another industry does not necessarily ensure its success in the alumina industry.

As stated in the original roadmap document, implementing the research activities in this updated 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.

The alumina industry should make renewed efforts via the BAC and the ATP 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 21<sup>st</sup> century.



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# Appendix A

## Priority R&D Needs

# PRIORITY R&D NEEDS

## Alternative Methods to Accelerate Precipitation Rates

Dissolved alumina is recovered from liquor in precipitation tanks seeded with alumina trihydrate crystals. The rate of precipitation depends on the temperature of the process, the concentration of the alumina hydrate and the caustic soda, the seeding process, impurities in the liquor, and other factors. Precipitation is typically very slow, necessitating the use of many large tanks.

**Potential Partners**

Alumina companies, academia, research organizations

**Potential Payoff**

High

**Technical/Economic Risk**

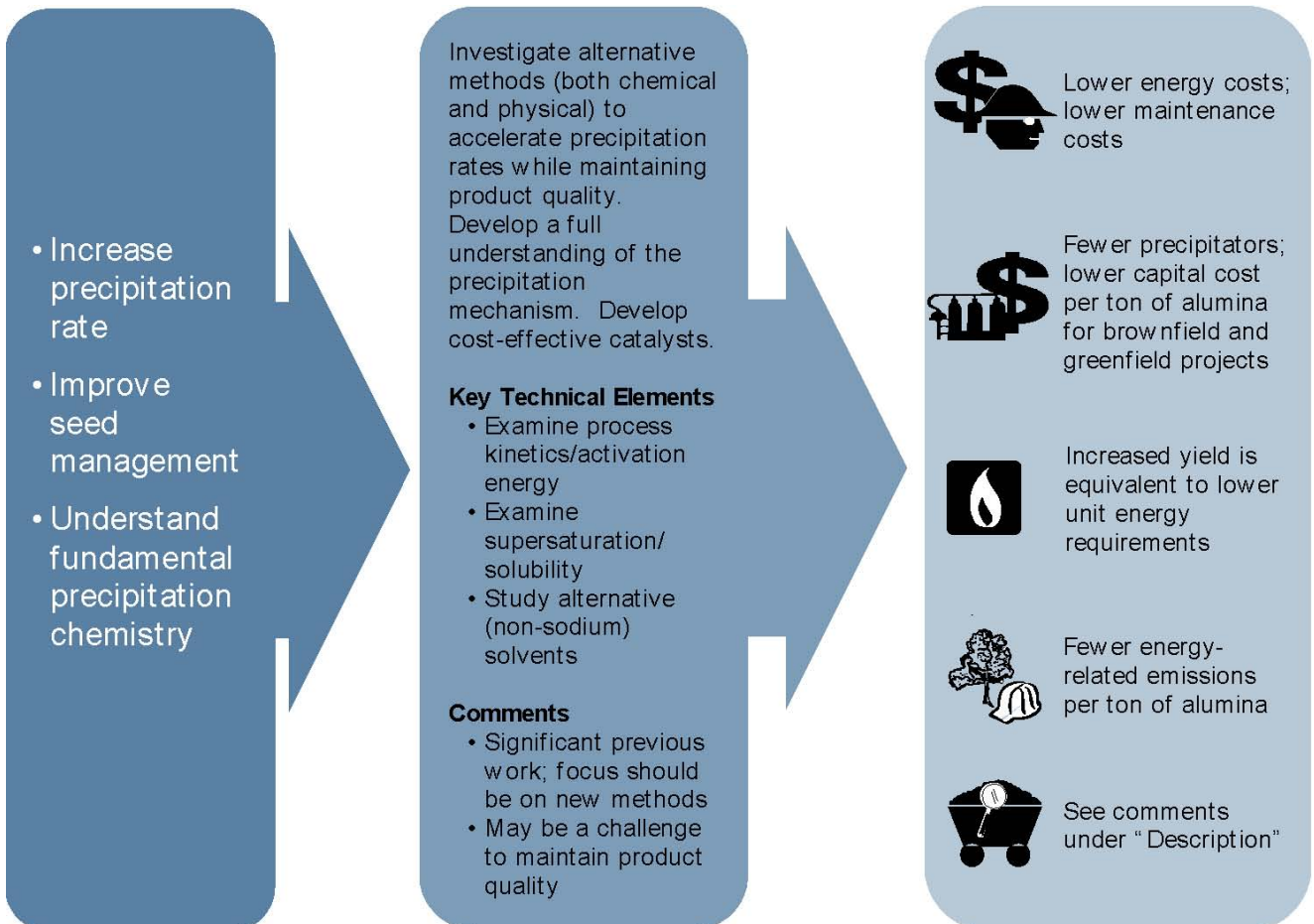
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Bauxite Residue: Cost-Effective Inerting and Alternative Uses

The sheer volume of bauxite residue generated at refineries, combined with its alkalinity and the cost of treatment and handling, are major constraints in finding economical applications for this byproduct. Rendering the residue inert would make it easier and cheaper to store in a sustainable form and would facilitate its use in many applications.

**Potential Partners**

Alumina companies (corporate level), government, industry associations, academia, research organizations, potential customers

**Potential Payoff**

Moderately high

**Technical/Economic Risk**

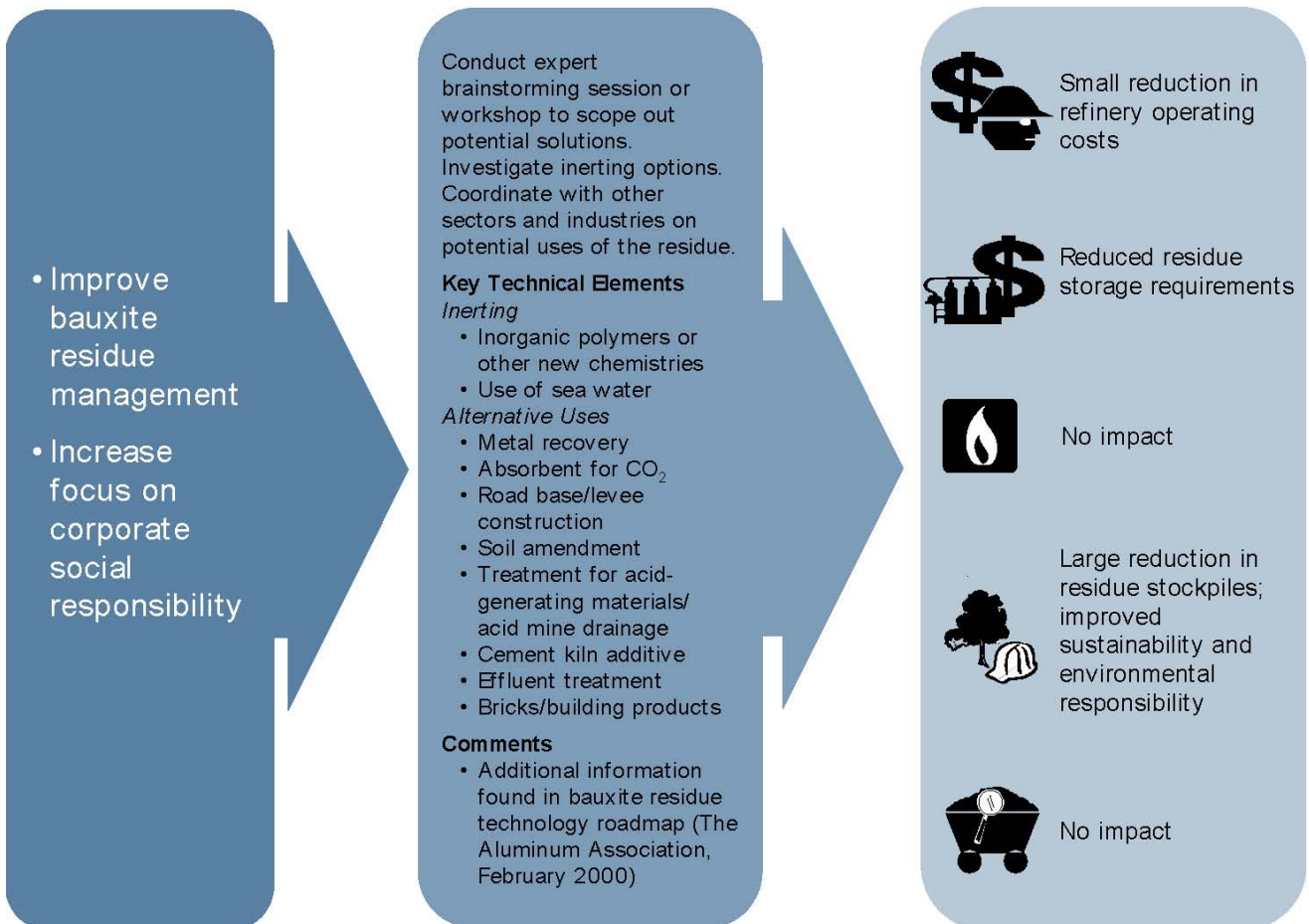
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Conversion of Monohydrate Bauxite to a More Beneficial State

A significant fraction of the bauxite being refined in the world today is monohydrate bauxite (boehmite or diaspore) that requires high-temperature digestion. Bauxite in the form of some intermediate state between monohydrate and trihydrate (gibbsite) could be digested at lower temperatures and would require less caustic and energy.

**Potential Partners**

Alumina companies, academia, research organizations

**Potential Payoff**

Moderate

**Technical/Economic Risk**

Moderate

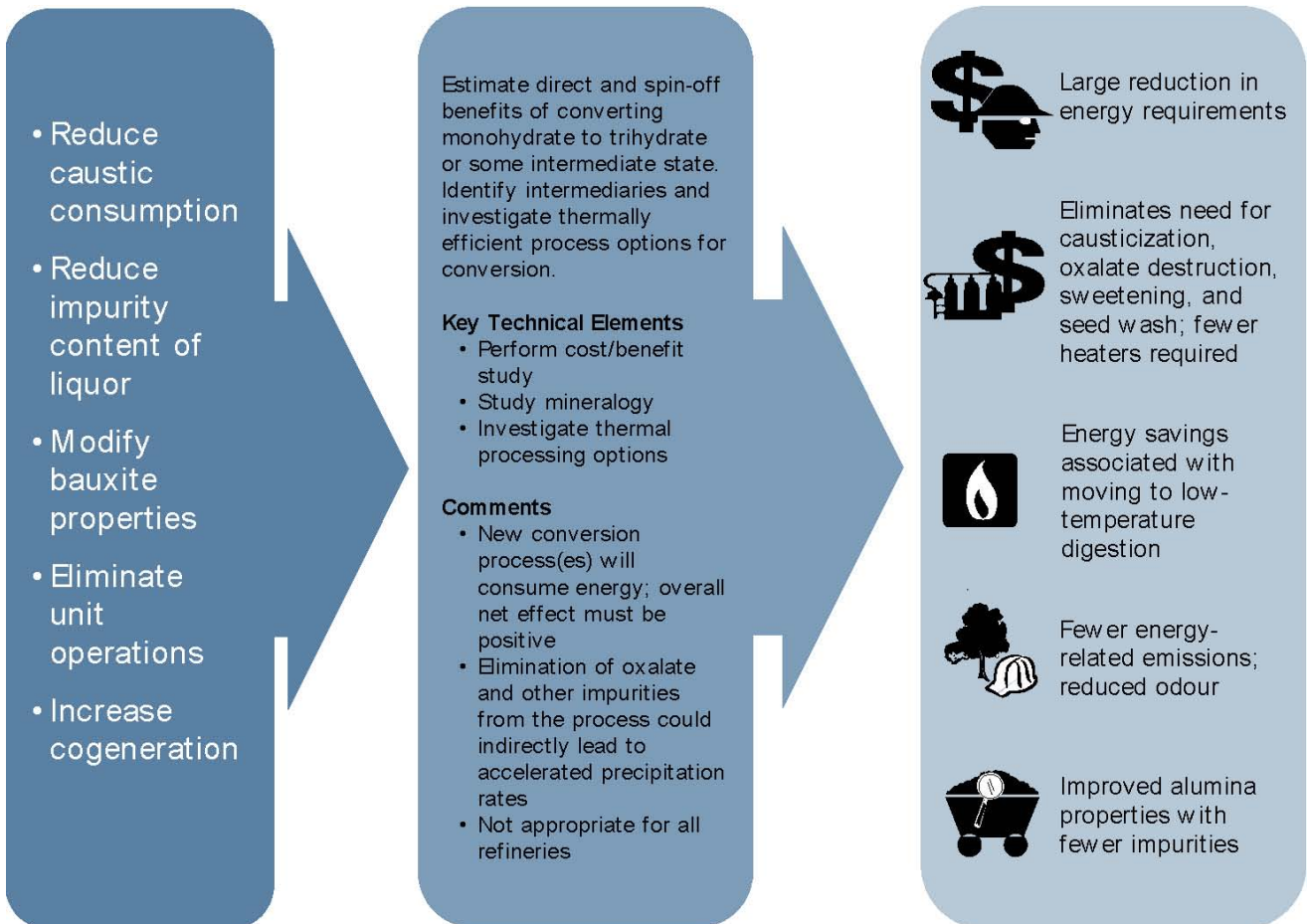
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Direct Reduction of Bauxite or Other Aluminium Materials

The development of a direct reduction process for producing aluminium from bauxite or other aluminium-bearing minerals could eliminate many of the problems associated with alumina production. Direct reduction could be combined with an aluminium refining process to produce aluminium with the desired quality. This new process would be a radical change from the current alumina/aluminium production route with major impacts on costs and energy consumption.

**Potential Partners**

Alumina companies, government, academia, research organizations

**Potential Payoff**

High

**Technical/Economic Risk**

High

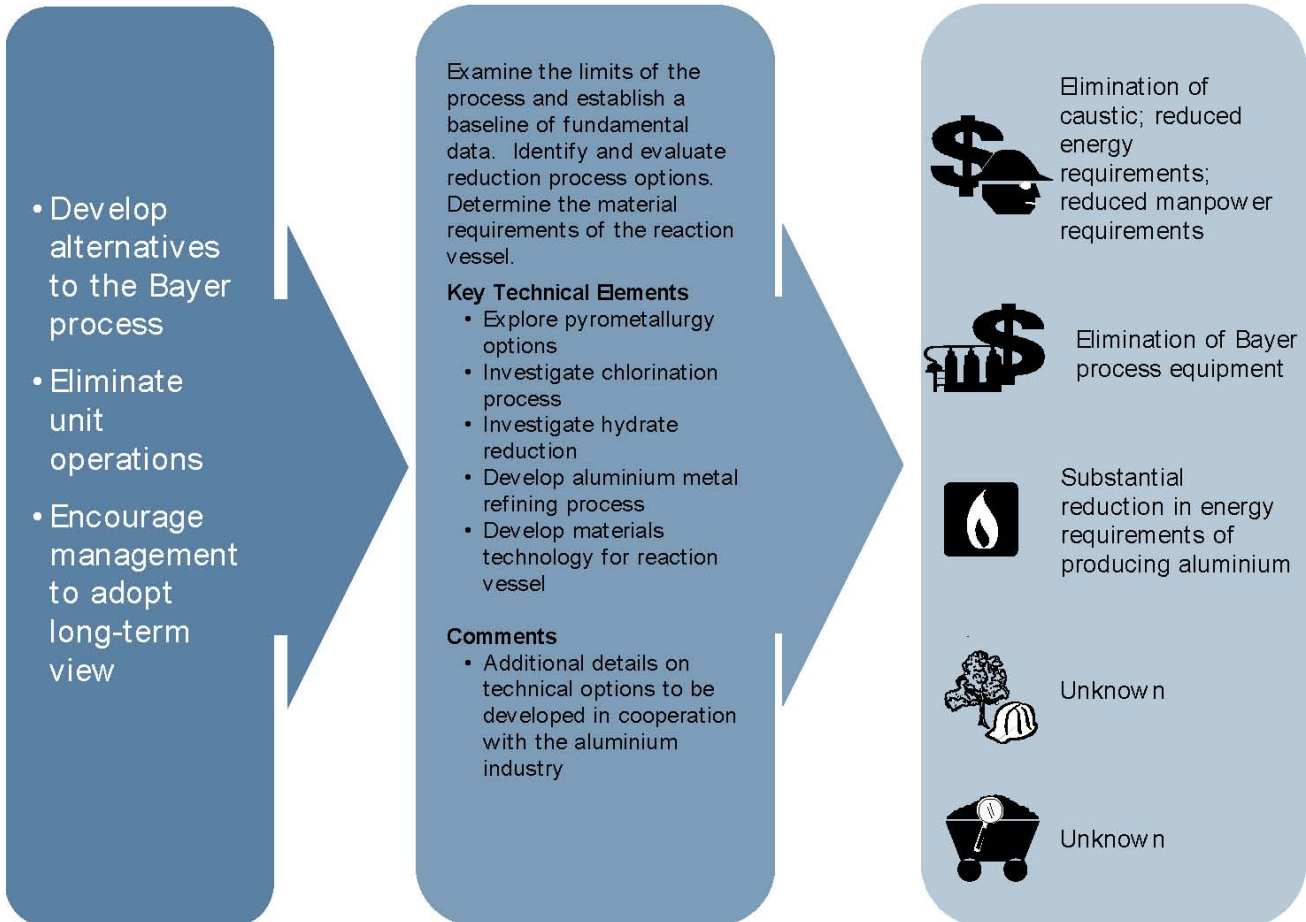
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Full Automation/Improved Control Strategies

The motivating factors for increased automation in the refinery are improved efficiency and productivity as well as reduced manpower requirements. Safety considerations also represent a key driver; automation reduces process upsets requiring human intervention in potentially dangerous environments. Automation can also lead to better product quality and consistency.

**Potential Partners**

Alumina companies, academia, research organizations, equipment and instrument suppliers

**Potential Payoff**

Moderate

**Technical/Economic Risk**

**Time Frame**



**Challenges**

**Description**

**Impacts**

- Improve process automation and control
- Use more capable processes and elegant design
- Improve seed management
- Minimize human exposure






Benchmark 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.

**Key Technical Elements**

- Develop new sensors and control software (e.g., for precipitation)
- Conduct dynamic modeling
- Investigate low-cost, on-line precision control (e.g., liquor analyzer)
- Develop expert systems and neural networks

**Comments**

- Some sensing methods don't work well in the refinery environment
- Continuous advances will be needed to achieve the long-term goal of full automation

-  Incremental improvements in productivity and energy efficiency; reduced labor requirements
-  Negligible impact
-  Small savings from better control of digestion and calcination
-  Reduced human interaction in potentially dangerous environments
-  Better product quality and consistency through improved process control and predictive modeling

# PRIORITY R&D NEEDS

## Impurity Removal: Bauxite *and* Bauxite Beneficiation

Efficient use of the world's bauxite resources requires maximizing both the quantity and quality of the alumina that is extracted. A major cause of Bayer process inefficiency is the introduction of impurities contained in the bauxite. The industry lacks technically and economically viable methods for controlling and removing these impurities. The trend toward lower grades of bauxite available in the future will only exacerbate this problem.

**Potential Partners**

Alumina companies, research organizations, government, suppliers

**Potential Payoff**

High

**Technical/Economic Risk**

Moderate

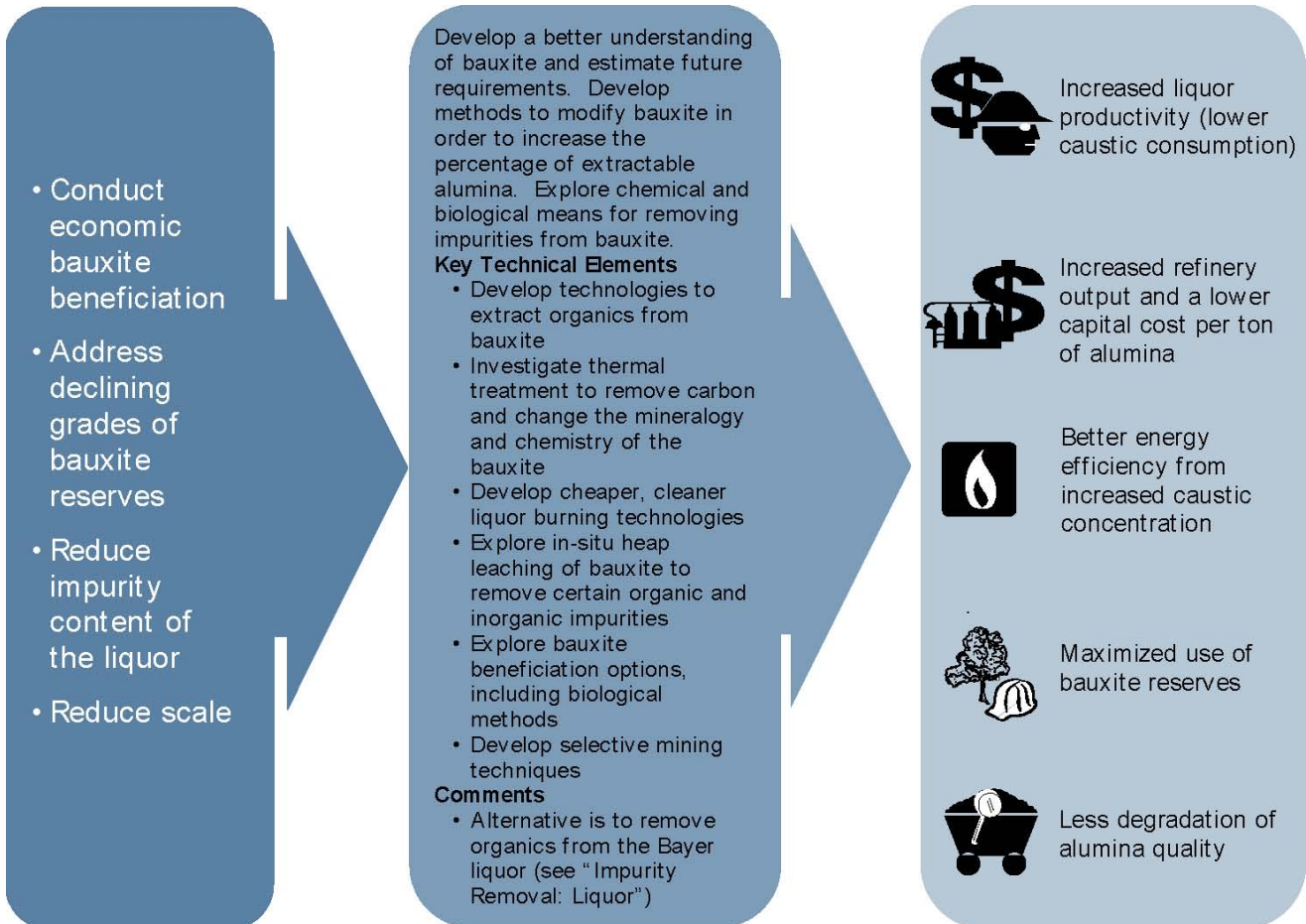
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Impurity Removal: Bayer Liquor

Almost all organic compounds enter the Bayer circuit with the bauxite. Inorganic impurities also are introduced via bauxite as well as caustic and makeup water. The presence of significant concentrations of impurities in the liquor has a detrimental effect on almost every aspect of the Bayer process, including digestion and precipitation capability, liquor productivity, and product quality.

**Potential Partners**

Alumina companies, academia, research organizations, government

**Potential Payoff**

Moderately high

**Technical/Economic Risk**

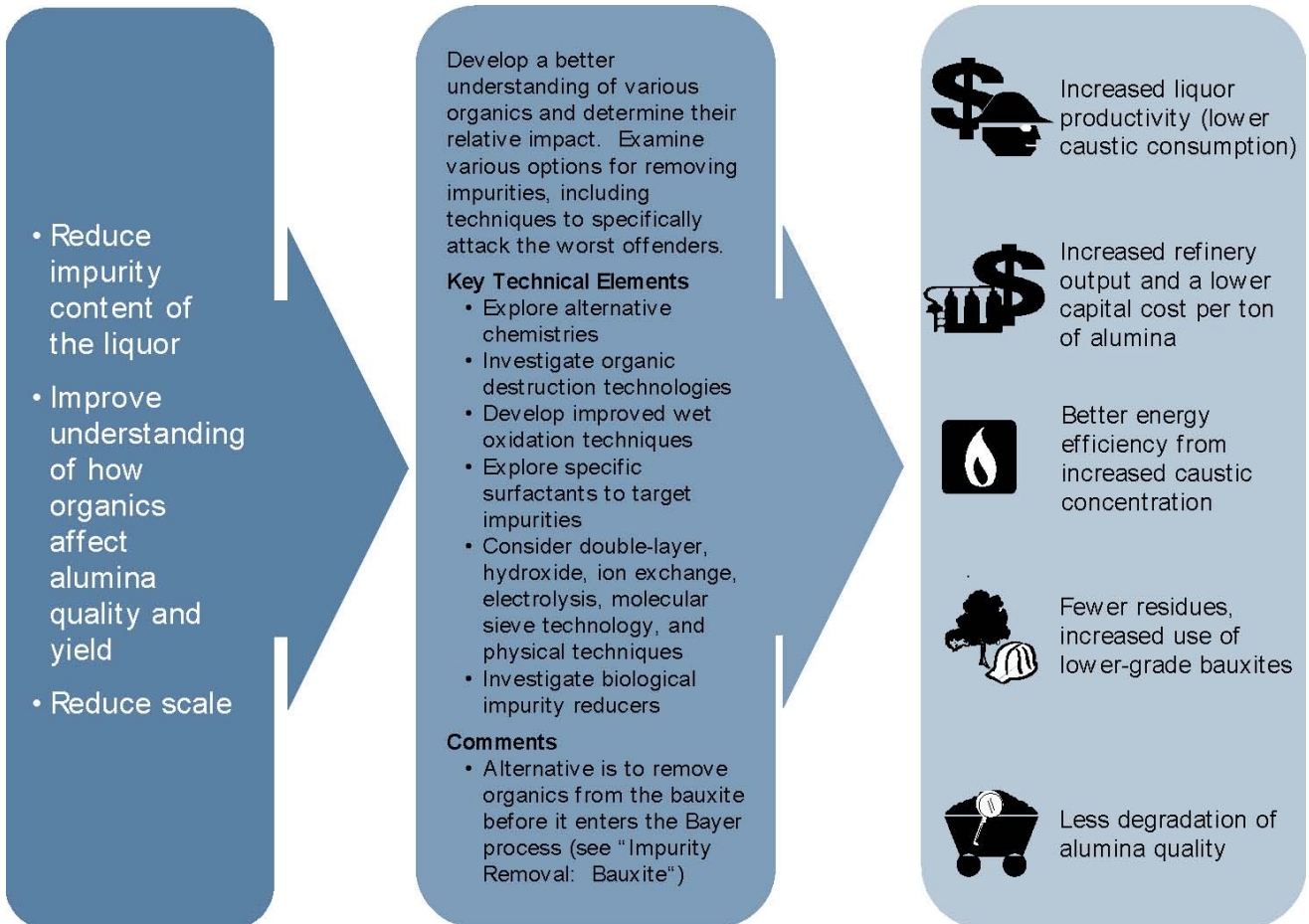
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Knowledge Management and Best Practices Benchmarking

The alumina industry lags behind the chemical and some other industries in terms of its use of process modeling to optimize operations, the sophistication of its control systems, its handling and treatment of raw materials and byproducts, and its safety culture. Poor knowledge management, particularly at the operations level, inhibits the industry's ability to improve its performance. Benchmarking may help the refining industry identify potential solutions to some of its key problems by learning from other industries.

**Potential Partners**

Alumina companies, government

**Potential Payoff**

Moderately high

**Technical/Economic Risk**

Low

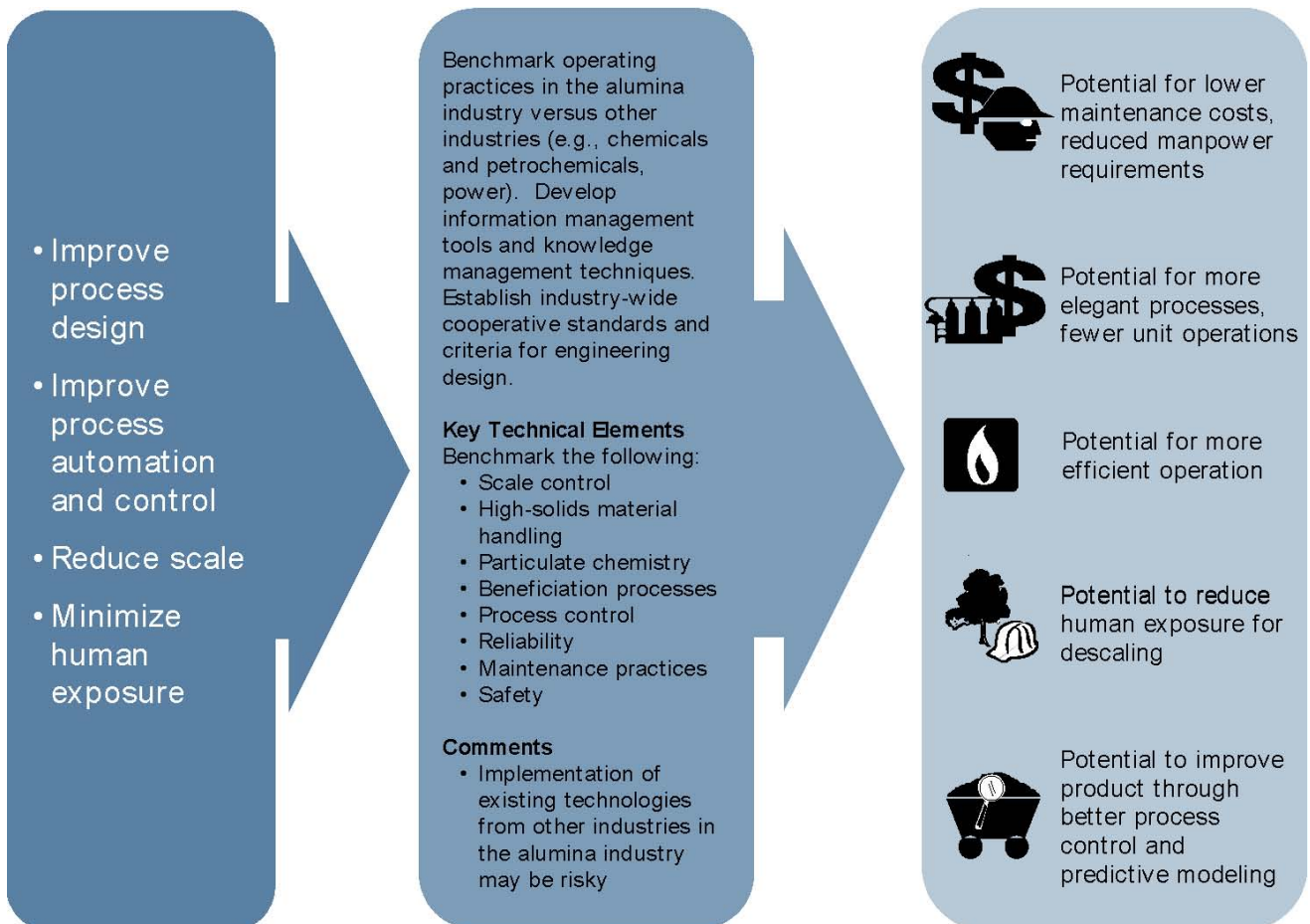
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Major Reduction in Caustic Consumption

The caustic soda used in Bayer liquor represents one of the largest operating costs in an alumina refinery. Major factors influencing caustic requirements are the composition of the bauxite being processed and the chemistry of the desilication product (DSP) formed during digestion. Much of the caustic soda content of DSP is currently unrecovered.

**Potential Partners**

Industry, academia, research organizations, government

**Potential Payoff**

High

**Technical/Economic Risk**

Moderately high

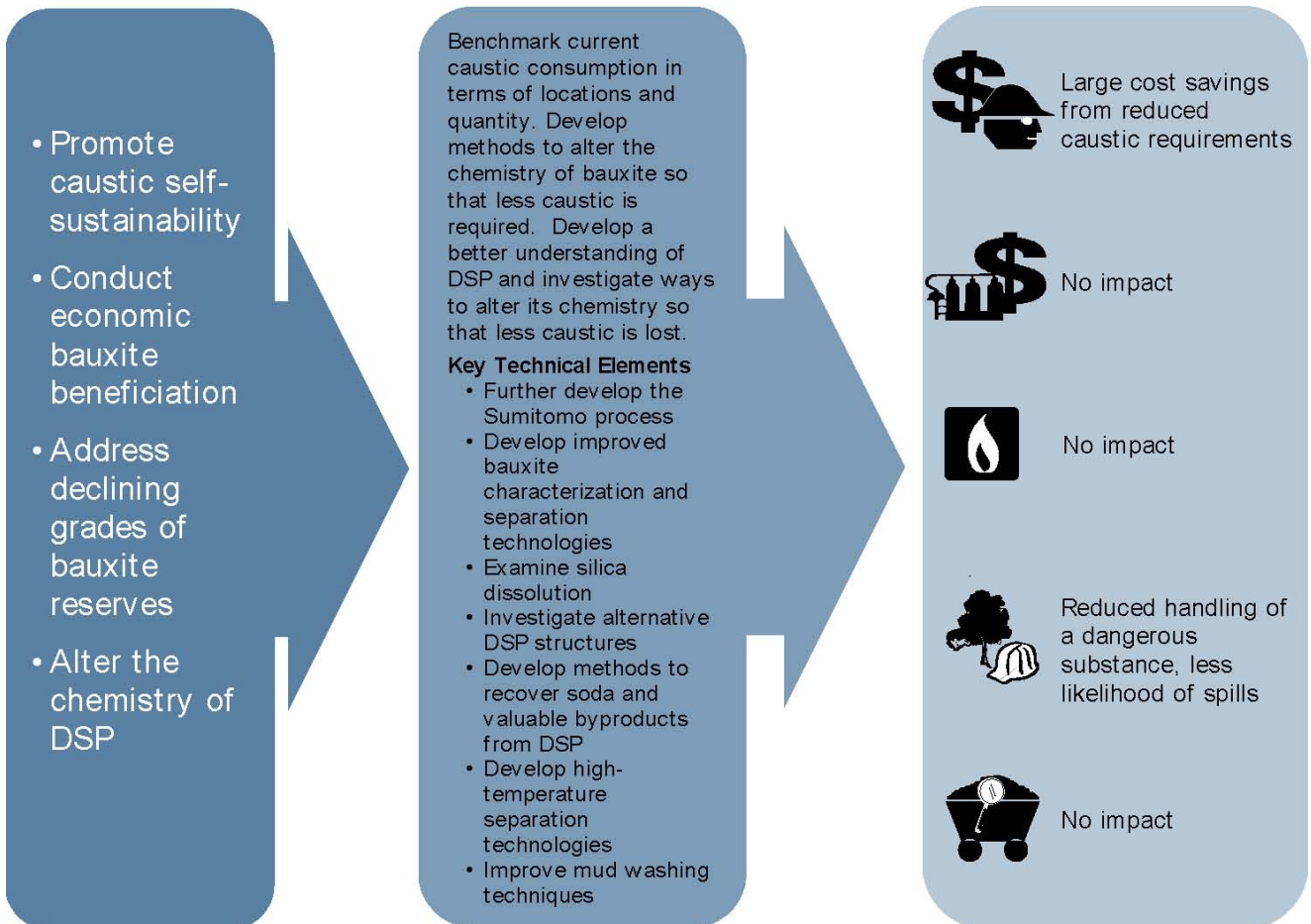
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Scale Management

The precipitation of sodium aluminosilicate crystals from spent Bayer liquor leads to scaling of heat exchanger vessels and piping. Other types of scale can occur elsewhere in the plant (e.g., calcium titanate-containing scale and alumina trihydrate scale). Maintenance personnel are required to remove scale manually, presenting a serious risk for injury because of the corrosive environment and enclosed space. Scale leads to a significant reduction in heat transfer efficiency and liquor throughput, resulting in increased energy and caustic soda consumption and loss of productivity.

**Potential Partners**

Alumina companies, academia, research organizations

**Potential Payoff**

High

**Technical/Economic Risk**

Moderately high

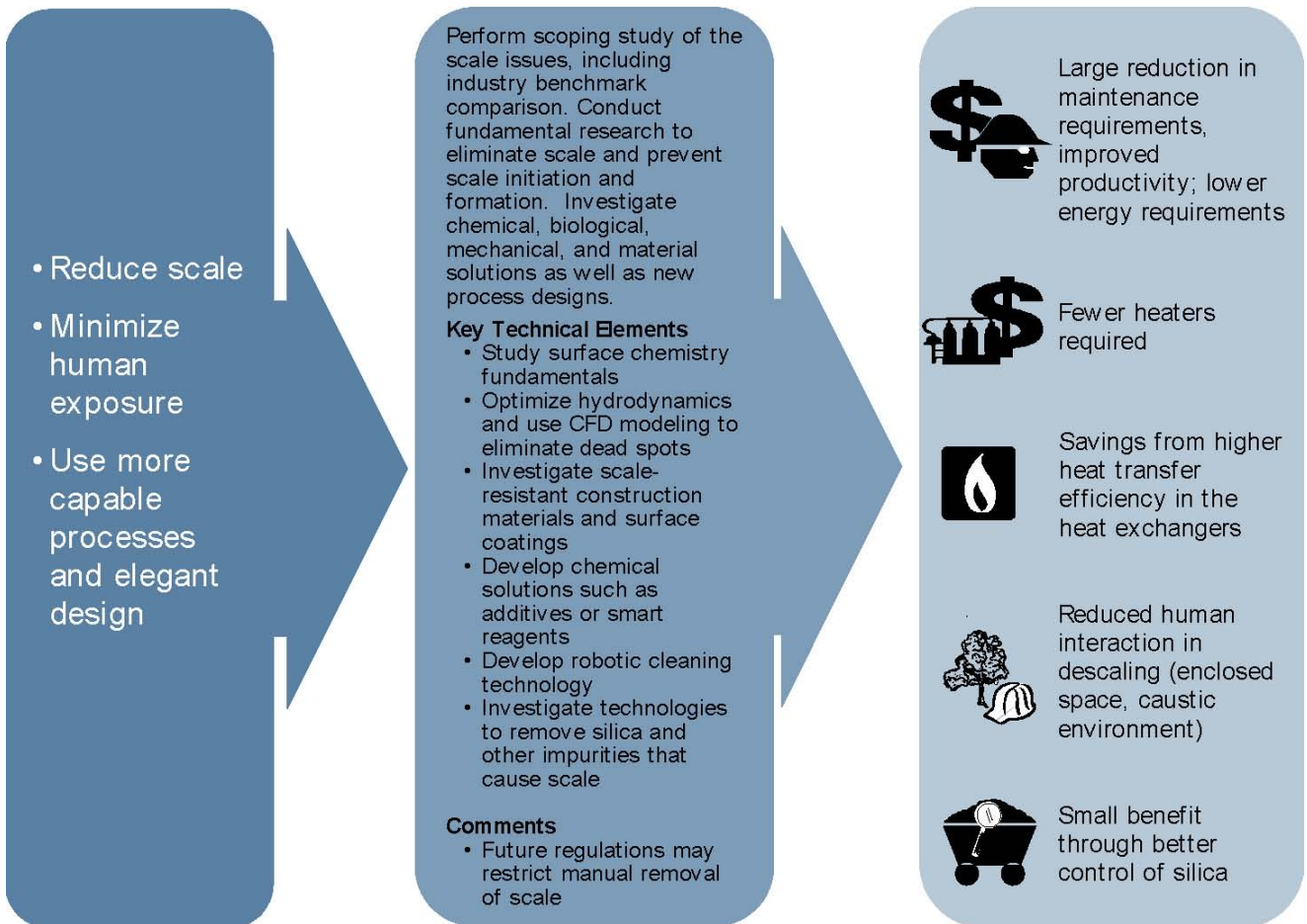
**Time Frame**



**Challenges**

**Description**

**Impacts**



# PRIORITY R&D NEEDS

## Technical Solutions for Refinery Releases

The issue of refinery releases (including air emissions, effluents, and solid wastes) is becoming more prominent and must be viewed from a broader perspective than in the past. Cost-effective solutions are needed to deal with caustic, organics, trace metals, particulates, and other releases. Insufficient attention has been given to groundwater contamination in particular.

**Potential Partners**

Research organizations, government, refineries, industry trade associations

**Potential Payoff**

Moderately high

**Technical/Economic Risk**

High

**Time Frame**



**Challenges**

**Description**

**Impacts**

- Reduce groundwater pollution
- Minimize water usage
- Minimize human exposure
- Increase focus on corporate social responsibility






Conduct scoping study to determine possible next steps. Investigate technical options. Share industry best practices.

**Key Technical Elements**

- Determine environmental impact at the boundary of the refinery
- Develop non-end-of-pipe removal of trace metals (e.g., selective mining)
- Conduct mixing zone estimation (e.g., toxicology studies, generic models)
- Develop better instrumentation and standardize design and practices to minimize spills
- Develop caustic spill management techniques other than concrete technology
- Model full mass balance to track all constituents

**Comments**

- Solutions are a mix of best practices and research activities
- May be needed for future operation/expansion

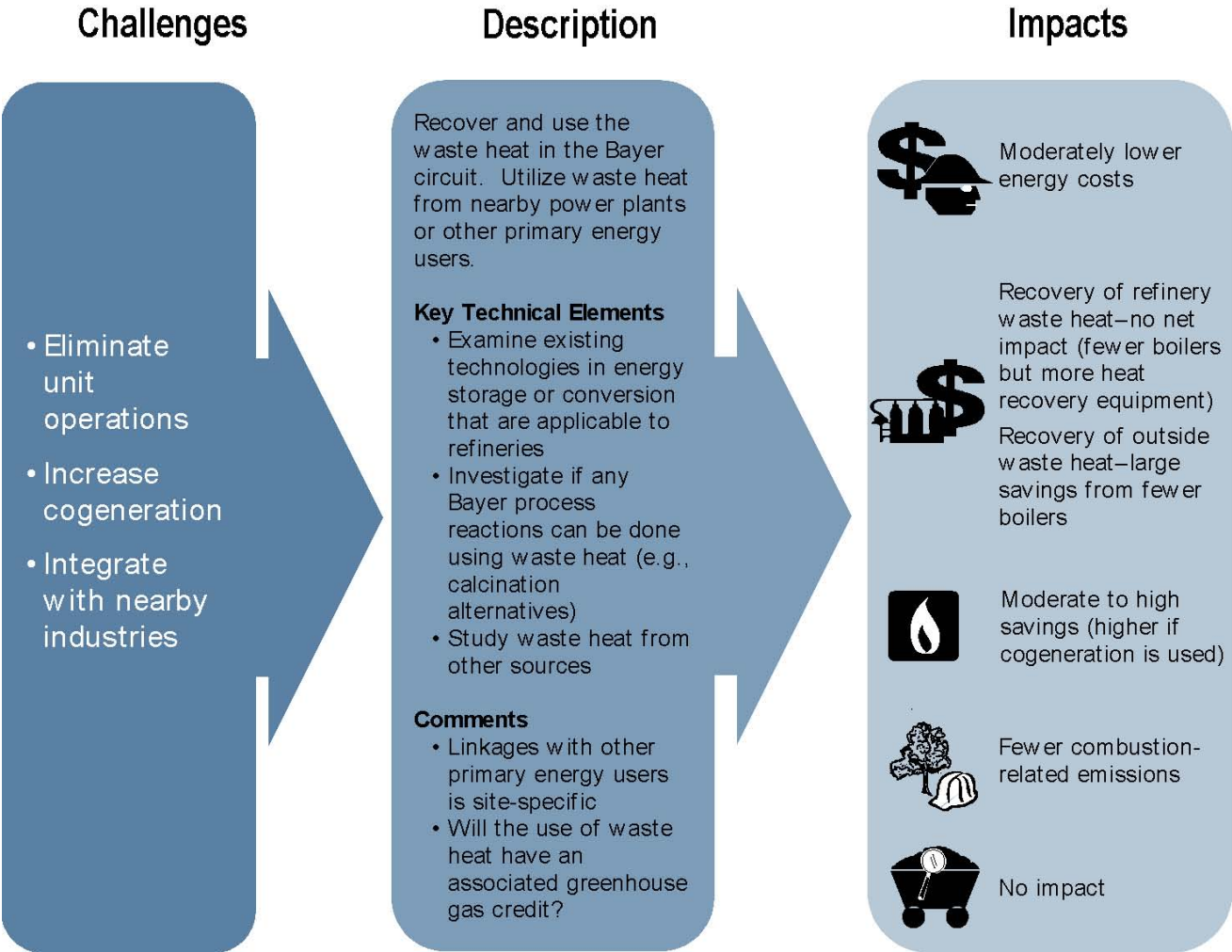
-  Small reduction in caustic consumption
-  No impact
-  Small opportunity to recover low-grade waste heat from flue gas
-  Reduction in air pollutant emissions, spills, and groundwater contamination
-  Provide "green" alumina to customers

# PRIORITY R&D NEEDS

## Waste Heat Recovery

The alumina industry is a large sink for low-grade heat and presents significant opportunity for cogeneration. The industry is currently not taking advantage of available waste heat, mainly because of economic and regulatory reasons. The initial focus should be on recovering waste heat generated in the refinery.

<b>Potential Partners</b>	Alumina companies, adjacent industries, government
<b>Potential Payoff</b>	Moderate
<b>Technical/Economic Risk</b>	Low







# Appendix B

## R&D Areas

# R&D AREAS

## Digestion

During the digestion process, the alumina contained in the bauxite is dissolved in the Bayer liquor in the form of sodium aluminate. R&D needs in digestion focus on reducing the energy requirements (e.g., by carrying out the process at lower temperature or using biotechnology), facilitating the use of different grades of bauxite such as those with more reactive silica and reducing caustic requirements. A specific activity would be research into altered desilication technologies that reduce sodium consumption, which would have a substantial payoff for refiners processing high-silica bauxite. The success of this effort would also significantly increase usable bauxite reserves. A true countercurrent digestion process for extracting monohydrate grades of bauxite at low-temperatures (using a vertical upflow vessel where the monohydrate is introduced at the top and the spent liquor at the bottom) would be a valuable progression of the “best practice” countercurrent technology currently used. The use of “free” evaporation (where entropy is used as a substitute for additional live steam) should also be investigated.

### Challenges

- Achieve higher alumina extraction efficiency
- Alter the chemistry of DSP Sustain higher supersaturation in the digester
- Reduce embrittlement in the digester
- Lower temperatures in Bayer operations
- Reduce caustic consumption
- Increase use of biotechnology
- Address declining grades of bauxite reserves

### R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"><li>Flexible digestion technology to accept variable grades of Bauxite</li><li>Free evaporation using entropy</li><li>Design of a real countercurrent digestion process to extract monohydrates at low temperatures</li></ul>	<ul style="list-style-type: none"><li>Non-milling digestion technology</li><li>Altered desilication technology with lower soda consumption</li><li>Technology for high alumina extraction at low temperature</li><li>Selective bauxite biodigestion</li><li>New digestion system for high-silica bauxite</li><li>Methods to eliminate coarse particles from the digestion circuit</li></ul>	<ul style="list-style-type: none"><li>Continuation of near- and mid-term activities</li></ul>

# R&D AREAS

## Clarification

Bauxite residue is separated from the liquor containing the dissolved sodium aluminate in a settling process, after which the residue is washed to recover caustic soda and any remaining aluminate liquor. Potential improvements to this process could include the elimination of security filtration, which would improve safety while decreasing capital and operating costs. Combining digestion and clarification into a single unit operation would improve the stability of these processes. If the combination process is continuous, it would represent a step change in current operations. An alternative to pressure decanter technology for the combined process would be a liquid/solid separation process utilizing membrane technology.

### Challenges

- Achieve higher alumina extraction efficiency
- Achieve better separation of components in the process
- Combine unit operations to reduce capital intensity
- Use more capable processes and elegant designs
- Reduce wash water requirements
- Reduce energy consumption

### R&D Activities

#### Near Term

- Pressure decanter to carry out both digestion and clarification at elevated temperature

#### Mid Term

- Low-wash soda

#### Long Term

- Alternative liquid-solid separation process for residue from liquor
- Alumina stabilizer that can be easily removed from pregnant liquor
- Elimination of security filtration

# R&D AREAS

## Precipitation

Alumina hydrate crystals are precipitated from Bayer liquor in a series of tanks seeded with gibbsite. The development of catalysts for reducing the activation energy for precipitation (as well as other Bayer process steps) could significantly improve productivity. Computer modeling techniques should be developed to improve the efficiency of designing these catalysts as well as other additives. An alternative to current precipitation operations would be to focus on the yield of the precipitation process and adjust the quality of the product afterwards.

### Challenges

- Increase precipitation rates
- Use more capable processes
- Improve seed management
- Reduce equipment residence time
- Increase use of lower-grade reagents
- Understand fundamental precipitation chemistry and physics

### R&D Activities

#### Near Term

- Continue ongoing projects aimed at incremental improvements

#### Mid Term

- Better seed management
- Molecular simulation of new reagents to promote rapid crystallization
- Highly energy-efficient agitators

#### Long Term

- Identification of a gibbsite precipitation catalyst
- Accelerated precipitation technology
- Computer modeling to design additives
- Countercurrent precipitation
- Methods to make quality *after* precipitation

## Calcination

Calcination represents one of the costliest and most energy-intensive operations in alumina refining. In calcination, the precipitated alumina hydrate crystals are sent to calciners or kilns where the water is removed. Several properties of the alumina product are very dependent on the conditions of the calcination process. The main focus of R&D is investigating potential means for improving the thermal energy efficiency of calcination. These efficiency gains must be sufficient to offset the high cost of retrofitting the calciner. Refiners and smelters need to collaboratively examine whether the trend toward decreasing smelting temperatures would affect calcination requirements. The quality of reprocessed calciner dust and technologies that activate it for use in the Bayer process also merit more research.

### Challenges

- Improve energy efficiency of calcination
- Lower the overall temperature in Bayer operations
- Increase use of waste Products

### R&D Activities

#### Near Term

- Determination of effect of lower Al smelting temperatures on calcination

#### Mid Term

- Study of oxygen-enrichment benefits of calcination
- Methods to reduce the temperature of calcination
- Technology that activates calciner dust for use

#### Long Term

- Continuation of near- and mid-term activities

# R&D AREAS

## New Process Chemistries and Alternative Raw Materials

The development of new process chemistries could eliminate many of the problems associated with alumina production (e.g., scale, impurities). Some options (the use of trona, for example) have been considered in the past but were unsuccessful. Other options include an aluminium chloride route to alumina production and the physical separation of monohydrates and trihydrates. New physical or chemical methods to reduce the amount of reactive silica that is dissolved or to remove kaolin from Bayer liquor before dissolution is complete are needed. The alumina industry also needs to establish a strategy for managing its use of resources in the future. The trend toward lower grades of bauxite and higher raw material costs will require the industry to maximize the use of its bauxite reserves, possibly through the use of alternative raw materials.

### Challenges

- Develop alternatives to the Bayer process
- Understand other process chemistries that may supplant Bayer
- Use more capable processes and elegant design
- Reduce scale
- Find cheaper sources of raw materials
- Address declining grades of bauxite reserves Encourage management to adopt long-term view

### R&D Activities

#### Near and Mid Term

- Study of simpler systems and analogy

#### Mid Term

- Dry particle separation for bauxite
- Physical separation of mono- and tri-hydrate
- Use of low-alumina laterites
- Economic use of trona
- Mechanical and chemical fine grinding technology and kaolin immobilization
- Kaolin complexation technology process agent
- Process for converting kaolin to absorbents
- Viable alternative caustic source
- Use of other caustic salts as solvents
- Solvent extraction technology for Bayer liquors
- Investigation of a chloride route (production of aluminum trichloride)
- Alternate means of inducing reactions (e.g., microwave)

## Product Characteristics and Quality

Alumina refiners and aluminum smelters need to work cooperatively on a number of issues related to alumina quality and properties. A solid fundamental understanding of alumina's chemical and physical properties and their variations will provide the framework for achieving consistent product quality. This will also enable refiners to tailor product characteristics to better meet their customers' needs. Better data on product characteristics may also indicate the potential use of beneficial process changes (e.g., calcining at lower temperatures) while still producing an acceptable alumina. New or revised product classification technologies are also needed, as are new measures for product quality itself. The refining industry could also work with smelters to redesign pot feeders capable of handling variable density alumina and to redesign dry scrubbing systems.

### Challenges

- Better rationalize product strength
- Develop better measures of product physical quality
- Improve fundamental understanding of product quality
- Develop better understanding of alumina's properties
- Increase cooperation with experts from other industries
- Improve coordination between suppliers and customers

### R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"><li>□ Improved method for attrition index/alumina dustiness</li><li>□ Scrubbing technology that uses weak alumina</li><li>□ Studies of alumina dissolution at low temperature</li><li>□ Study of product variability</li></ul>	<ul style="list-style-type: none"><li>□ Cooperative effort with customers to redesign pot feeders to handle variable bulk densities of alumina and fines</li></ul>	<ul style="list-style-type: none"><li>□ Continuation of near- and mid-term activities</li></ul>

# R&D AREAS

## Controls and Instrumentation

Advances in process controls, instrumentation, and measurement techniques are key to the long-term goal of full refinery automation. Achieving a high level of process control without significant human labor requires instrumentation that is precise, reliable, and robust. Reliable instruments that are specific to alumina refining are needed to measure common parameters such as temperature, pressure, density, and flow. New on-line measurement techniques and robust sensors are also needed for parameters specific to the Bayer process such as A/C and caustic analysis. The use of “at-line” instrumentation — a variation of on-line instrumentation that is not in continuous use (and therefore not constantly subjected to the corrosive stream) — could add operational flexibility by providing the feedback needed to make corrections without the delay associated with lab results. Other research needs include the development of new in-situ techniques that will survive in sodium chemistry; remote sensing technology (e.g., ultrasonics) that can evaluate material thickness and defects without opening up equipment; and industry-specific control valves that are cheap, low pressure-drop, non-scaling, and reliable for use in liquor and slurry applications.

### Challenges

- Improve process control and develop more online instrumentation and measurement techniques
- Increase process automation
- Reduce manual labor requirements
- Develop more process optimization tools and techniques
- Improve knowledge management at the operations level
- Develop efficient isolation valves
- Use more capable processes and elegant design

### R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"><li>□ Better plant sampling methodologies and techniques</li><li>□ Use of new developments in chemometrics</li><li>□ Bayer-specific sensors for particle size, caustic, A/C</li><li>□ In-situ techniques that will survive in sodium chemistry</li><li>□ Remote sensing (e.g., ultrasonics) to examine material or scale thickness</li></ul>	<ul style="list-style-type: none"><li>□ Industry-specific control valves, isolation valves, isolation valves, and pumps for liquor and slurry</li><li>□ At-line instrumentation (simple, robust, real-time, operator-controlled)</li></ul>	<ul style="list-style-type: none"><li>□ Specifications for sensing of common parameters (i.e., temperature, pressure, density, flow) reliably and accurately</li></ul>

## Models and Tools/ Process Management

Accurate, validated models can allow more effective management of the refinery from both a process and an economic point of view. Better understanding of what is happening in each process step will help refiners optimize operations and increase throughput. The industry needs to create tailored tools that will allow alumina companies to achieve “best practice” status. Models that incorporate economic factors are also needed; capital efficiency is an area where the refinery industry suffers in comparison to other industries. A refinery tool for capital process optimization could offer the potential for large savings by sharing knowledge between companies. In addition, the industry could develop an alumina/aluminium process model to determine whether certain process steps could be shifted from refineries to smelter operations in order to reduce overall costs, energy use, or waste generation.

### Challenges

- Develop more process optimization tools and techniques
- Increase process automation Improve knowledge management at the operations level
- Optimize the efficiency of the overall process Improve accounting of full product life cycle
- Use more capable processes and elegant design

### R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"> <li><input type="checkbox"/> Industrial process model (continuously updated; contains equipment reliability data)</li> <li><input type="checkbox"/> Capital process optimization tool</li> <li><input type="checkbox"/> Use of lean manufacturing</li> <li><input type="checkbox"/> Technology</li> <li><input type="checkbox"/> Methodology to convert process parameters to key performance indicators</li> <li><input type="checkbox"/> Methodology to maximize equipment up-time</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Life-cycle modeling (including environmental factors and cost)</li> <li><input type="checkbox"/> Process model (including energy and waste data) to define optimal break points</li> <li><input type="checkbox"/> Modularization and optimization of plant layout</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Techno-economic model of the Bayer process (validated computational modeling of process steps)</li> </ul>

# R&D AREAS

## Knowledge Management

Gathering and managing information on developments within the alumina industry as well as those in related industries is critically important to improving competitiveness. The alumina industry tends to be quite insular and does not typically look for solutions from other industries, even those facing the same issues as refiners. The development of an information infrastructure for the industry will allow companies to avoid duplication of efforts and take advantage of shared knowledge. Suggested actions include developing a Bayer-sector data base with common units and finding ways to utilize the wealth of Bayer plant knowledge (particularly on instrumentation) in the Eastern Block. A potentially major event would be an examination of the Bayer process by world-class organic chemists and separations technologists, who would be asked to recommend improvements or even entirely new ways of producing alumina. Finally, the industry needs a guide on how to approach local communities when moving into new countries to find bauxite reserves.

### Challenges

- Improve knowledge management at all levels, particularly operations
- Work with all levels of plant personnel to develop solutions to problems
- Develop new processes and technologies for producing alumina
- Keep alumina industry ahead of the curve on dealing with new issues (e.g., environmental)
- Increase focus on corporate social responsibility

### R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"><li>□ Cooperative efforts with other industries to look for ideas and synergies</li><li>□ Invitation to world-class scientists to evaluate Bayer process</li><li>□ Industry-wide process model to manage knowledge</li><li>□ Expert systems that capture existing knowledge</li><li>□ Techniques to utilize knowledge in the Eastern Block</li><li>□ Guide on how to approach communities on exploration and mining</li></ul>	<ul style="list-style-type: none"><li>□ Study of the theoretical and technical limits of existing processes</li><li>□ Bayer-sector common data base</li></ul>	<ul style="list-style-type: none"><li>□ Continuation of near- and mid-term activities</li></ul>

## Energy and Fuels

Energy use and process efficiency are key drivers for many process-related issues in the refinery. Reducing the time spent on unit operations such as digestion and precipitation, increasing product yield, and adopting on-line instrumentation all make the overall refining process more efficient. The lack of plant-wide energy balance models makes it difficult to optimize plant thermal efficiency and use of waste heat. The development of process-specific models for condensate and steam balance would reduce water consumption in addition to energy requirements. In terms of power generation, on-site cogeneration is more efficient and has fewer associated greenhouse gas emissions than purchasing power. One of the most efficient and environmentally friendly options would be the use of a coal-gasification combined-cycle system to cogenerate electricity and process steam.

### Challenges

- Consider thermal efficiency on a system basis
- Optimize the efficiency of the overall process
- Achieve 16 MW/petajoule of cogeneration industry-wide
- Reduce greenhouse gas emissions from energy use
- Overcome the difficulties and cost associated with demonstrating new technology

### R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"> <li><input type="checkbox"/> Improved condensate and steam balance</li> <li><input type="checkbox"/> Full model of plant-wide energy balance</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Use of geothermal and solar power to supplement energy requirements</li> <li><input type="checkbox"/> Methods to improve the efficiency of power houses</li> <li><input type="checkbox"/> Methods to build power interruptability into the plant (e.g., different levels of gas turbine output)</li> <li><input type="checkbox"/> Methods of apply combined cycle system and still use coal efficiently</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Utilization of organics in bauxite for energy</li> <li><input type="checkbox"/> Coal combustion technologies that give cogeneration capabilities (e.g., low-capital coal gasification)</li> </ul>

# R&D AREAS

## Bauxite Residue

Bauxite residue, or red mud, is the largest environmental concern of alumina refineries mainly because of the size of this waste stream and its causticity. Much effort has already been put into developing improved dewatering techniques, disposal technologies, and alternative uses. The alumina industry recognizes that it has a cradle-to-grave responsibility for the residue and that more work is needed to develop reuse opportunities and sustainable storage options. One option may be to neutralize the residue in-situ rather than build up large inventories. Improved methods of separating the components of the residue may ease neutralization and reduce the need for future remediation. This may include development of processes to extract valuable materials such as titanium or even organics from the residue. (Note: more detailed information can be found in the Technology Roadmap for Bauxite Residue Treatment and Utilization.)

### Challenges

- Improve bauxite residue management
- Develop economic applications for bauxite residue
- Increase focus on corporate social responsibility

### R&D Activities

#### Near and MidTerm

- Methods to produce a residue with high solids content and the required rheological properties
- More efficient fine particle classification
- Further development of high-temperature separation technology
- Process for extracting useful components from residue
- Examination of land reclamation alternatives

#### Mid Term

- Viable technology to neutralize residue
- Single-stage washing of residue
- Separation of residue into components to facilitate neutralization

## Releases

Refinery odours are an issue for on-site personnel as well as refinery neighbors. Most odours are a consequence of the emission of low-grade heat in the form of vapor, which also represents a direct energy loss. An industry-wide database defining the origins of organic vapors should be created for the worst compounds contributing to plant odours. The toxicological effects of emissions of mercury and other compounds are not often clearly understood, creating the need for a health assessment of all refinery emissions. Refineries consume large amounts of water; new effluent treatment technologies and techniques to reduce groundwater pollution can help the industry minimize its water use. Better technologies for reducing flue gas emissions are critical for those refineries burning oil or coal.

## Challenges

- Reduce or eliminate groundwater pollution
- Minimize water usage
- Better understand and control toxic emissions
- Reduce mercury emissions
- Eliminate refinery odours
- Increase use of waste products

## R&D Activities

### Near and Mid Term

- Health assessment of all emissions
- Inexpensive way to completely detect organic vapors
- Identification of specific compounds with high level of odour
- Flue gas emission reduction technology
- Bioremediation to address groundwater problems
- In-situ barriers technology to control groundwater
- Downstream uses for oxalate

### Mid Term

- Low-cost effluent treatment technologies

# R&D AREAS

## Minimization of Human Exposure and Improved Safety: Technology and Training

Improved materials of construction and processes that are designed with a focus on eliminating human exposure are particularly important in improving the safety of alumina refineries. Techniques to reduce workforce requirements for maintenance will also reduce human exposure to potentially harmful conditions. Training and education programs on safety and the development of systems for housekeeping and health will help establish a safety culture within the alumina refining industry. The acceptance and adoption of behavioral-based safety by plant personnel will be key. Based on the petrochemical industry model, for example, refiners can establish industry-wide cooperative standards for ES&H in engineering design.

### Challenges

- Reduce human exposure
- Create better safety systems and supporting culture
- Reduce manual labor
- Establish standards for hazardous operations
- Increase focus on corporate social responsibility

### Technology R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"> <li><input type="checkbox"/> New materials for conveyor belts to reduce noise</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Designs to eliminate human exposure</li> <li><input type="checkbox"/> Improve materials for piping and tanks to reduce exposure</li> <li><input type="checkbox"/> Scale removal techniques</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Safer heat transfer medium than steam</li> </ul>

### Training R&D Activities

Near Term	Mid Term	Long Term
<ul style="list-style-type: none"> <li><input type="checkbox"/> Virtual reality for safety hazard training</li> <li><input type="checkbox"/> Education programs on safety procedures</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Behavior-based safety (education and standards)</li> <li><input type="checkbox"/> Uniform industry cooperative standards for ES&amp;H</li> <li><input type="checkbox"/> Standardization of pressure</li> </ul>	<ul style="list-style-type: none"> <li><input type="checkbox"/> Continuation of the near- and mid-term activities</li> </ul>



# Appendix C

## Members of the International Aluminium Institute's Bauxite & Alumina Committee

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# Appendix D

## List of Acronyms

A/C	Ratio of alumina to caustic
CFD	Computational fluid dynamics
DISR	Australian Department of Industry, Science and Resources
DOE/OIT	U.S. Department of Energy, Office of Industrial Technologies
DSP	Desilication product
ES&H	Environment, safety and health
MW	Megawatt
R&D	Research and development
U.S.	United States
VOCs	Volatile organic compounds

