

**INTERNATIONAL COMMITTEE FOR STUDY OF  
BAUXITE, ALUMINA AND ALUMINIUM  
ICSOBA  
NEWSLETTER**



A biannual publication

**Volume 14 – December 2015**

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The picture on the front page is an aerial view of Dubai City, where the ICSoba 2015 Conference was held.

In case you consider publishing in this forum, please contact the editor before writing your article.

Deadlines for a June issue is 10<sup>th</sup> of June and for a December issue 10<sup>th</sup> of December.

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**FOREWORD**

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Dear ICSOBA Members!

Goa - 2011, Belem - 2012, Krasnoyarsk - 2013, Zhengzhou - 2014 and this year Dubai – all mark ICSOBA's recent stops on its global mission. ICSOBA has never been to this part of the world before; therefore, the Dubai conference was of historic importance in a year which marks the 52<sup>nd</sup> anniversary of our association. It was a pleasure to see so many of you in Dubai earlier this month. You will be pleased to hear that the event has grown in size this year and it continues to be a great forum for networking. Altogether 230 delegates participated from 38 countries. Through their discussions and presentations the delegates have made important contributions to the mining and treatment of bauxite, and the production of alumina and aluminium. We all have a lot of appreciation to those who made it happen, and achieve remarkable success on the way!

ICSOBA wants to thank those who made this Conference possible. First, the EGA organization – the host sponsor of this event, and people such as: Mohammed Yahya, Ali Al Zarouni, Abdalla Alzarooni, Mohamed Mahmoud, Yunus Dohadwala, Khalid

Bukumaid, Abdulwahab Almadani and Hend Belsehlah.

Tremendous and tireless effort of several individuals who last year agreed to become organizers resulted in exceptional technical sessions. Among the program organizers & subject chairman we have: Michel Reverdy (EGA), Roberto Seno (Votorantim), Steve Healy (Rio Tinto), Vinko Potocnik (EGA), Victor Buzunov (Rusal) and Matthieu Arlettaz (R&D Carbon). The conference proceedings (TRAVAUX) volume No. 44 of this year contain almost 100 papers and clearly represent the highest editorial level of ICSOBA proceedings that have appeared thus far.

A major responsibility of ICSOBA's directors is to ensure continuity of the organization. ICSOBA has been around for more than half century and it has been a very helpful and successful forum for aluminum industry professionals. Over the decades, ICSOBA's mission has evolved but its accomplishments remain, in my opinion, very beneficial for individuals involved and for the industry as a whole. Therefore, the ICSOBA vocation should continue and industry should maintain support for ICSOBA. And I think that what is best for ICSOBA is to maintain its roots and also encourage strong representation of senior industry members. Without their presence in the governing body, ICSOBA may not get far. In order to accomplish this, an important structural change took place. Last year we initiated a rotation of the post of President, who is chosen from the organization that hosts each year's ICSOBA event (read more in ICSOBA Matters).

As we continue to edit the NEWSLETTER, we welcome guest authors who are interested to share their experience and expertise with our readers. It is an excellent opportunity for guest authors to showcase their company profile, products, services, technologies, etc. on a global platform. If you have something interesting to share with your colleagues, please come forward and submit a note or an article for publication in the NEWSLETTER. In this edition, in fact, you will find very interesting contributions; by Ken Evans, PhD, by Prof. Fathi Habashi and by Prof. Houshang Alamdari. Enjoy reading.

I am very appreciative of all of the comments that I have received from many of you, whether during the Conference in Dubai or in response to my letters, phone calls and emails. I am privileged to enjoy your trust, and continue to influence an organization with such great enthusiasm and ideas amongst its members. I invite you to provide further input.

With the annual ICSoba conference in Dubai now concluded, and the New Year on the horizon, there is one last stop to make before ringing in 2016. New Year's Eve is one of the biggest parties in the world, with people from Goa to Belem to Krasnoyarsk to Zhengzhou to Dubai gathering with friends, family and sometimes even with complete strangers to usher in another 365 days. While enjoying the best moments of this passing year, please remember ICSoba and the New Year full of exciting new possibilities.

Dr Frank R. Feret

CEO, Vice President, ICSoba

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**NEWS AND EVENTS**

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# 34<sup>TH</sup> CONFERENCE AND EXHIBITION ICSoba-2016

## 34<sup>th</sup> Conference and Exhibition, ICSoba-2016

### INVITATION

**Dear Colleagues,**

It is with great honour that the International Committee for the Study of Bauxite, Alumina & Aluminium (ICSoba) announces its 33<sup>rd</sup> International Conference and Exhibition. The event will be held in Quebec (Canada) at the Hotel Palace Royal of Quebec from 3 to 6 October, 2016 in cooperation with Rio Tinto Alcan and the “REGAL”.

#### **Conference Objectives:**

- Review the status of bauxite, alumina and aluminium industries in the world with emphasis on Canada
- Discuss promising research developments aimed at production, productivity and cost improvements
- Highlight proposed greenfield and brownfield activities in the aluminium industry
- Discuss developments in the field of environment and safety
- Facilitate networking between academia and industry
- Update market aspects of bauxite, alumina and aluminium and their products
- Provide a strong platform to interact with international experts, scientists, engineers, technology suppliers, equipment manufacturers and representatives of aluminium industries the world over.

We look forward to meeting you at the ICSoba 2016 Conference in October.

*Claude Vanvoren, Vice President - Technology and R&D, Rio Tinto*

*Dr. Frank Feret, CEO, Vice President, ICSoba.*

For detailed information about ICSoba 2016, including conferences & exhibitions, please visit [www.icsoba.org](http://www.icsoba.org).

### **Note Regarding Hotel Reservation for ICSoba 2016 in Quebec**

Please note that for the needs of ICSoba 2016, 100 rooms have been reserved in the Palace Royal hotel for each conference day, starting with Saturday, October 2<sup>nd</sup>. The following special rates (in CAD\$) have been negotiated:

1. Hospitality room
  - Single occupancy: \$193.79
  - Double occupancy: \$207.59
2. Hospitality Suites (outside view)/deluxe room.
  - Single occupancy: \$213.79
  - Double occupancy: \$227.59

Room reservation can only be carried out directly with the hotel on an individual basis. The **Palace Royal hotel** does not appear on popular websites, such as Expedia, Trivago, etc. Given a limited number of rooms at Palace Royal please make a suitable room booking as early as possible.

**TO MAKE A RESERVATION: Group number # 3507321**

\* **By Internet : [www.hotel sjaro.com](http://www.hotel sjaro.com)**

\* **By Phone: 1-800-567-5276 or at 1-418-694-2000**

## **Program**

- I. Keynote session (October 3)
- II. Poster session and JER oral presentations – REGAL (October 3)
- III. Technical Sessions (October 4-5)
  - Bauxite and bauxite resources
  - Alumina production
  - Aluminium reduction
  - Carbon and carbon materials
  - Casting and fabrication
  - Economics, finance, projects in mining and metallurgy
  - Regional dynamics
  - Market analysis
  - Upstream and downstream challenges and opportunities
  - Environment, health and safety
  - Operational excellence and productivity
  - Innovation technology
- IV. Round-Table Discussions
- V. Technical Field Trips on October 6

## Technical field trips:

- Rio Tinto AP-60 smelter in Saguenay (Oct. 6)
- Vaudreuil Alumina Refinery (Oct. 6)

## Call for papers

The Organizing Committee is inviting the submission of papers. Enquires and abstracts should be sent to [info@icsoba.org](mailto:info@icsoba.org) Abstracts should include the title, the text not exceeding 200 words, the author's name(s), affiliation, position and e-mail address of the corresponding author.

## Deadlines for sending abstracts and manuscripts

Abstracts: 15 May 2016  
Full papers: 30 July 2016  
Presentations: 15 September 2016

## Organizing Committee

General coordination: Dr Frank Feret (ICSoba)  
Claude Vanvoren (Rio Tinto)

Speaker Program: Michel Reverdy (EGA)  
Prof Houshang Alamdari (Laval University)

## Sponsorship opportunities

For details regarding sponsor benefits click on the link below

<http://icsoba.org/sponsors>

For filling up the sponsor form click on the link below

<http://icsoba.org/form/sponsor-registration-form>

## Corporate member

For becoming a corporate member click on the link below

<http://icsoba.org/form/corporate>

## Subsidies to Members

Members who have insufficient means to pay the cost of participating in an Event may apply for a subsidy. The details can be found on Page 8 in the 13 Newsletter, June 2015.

## Bauxite Residue Valorisation and Best Practices Conference, BR 2015

The Bauxite Residue Valorisation and Best Practices conference was an informative and successful event in Leuven, Belgium from 5 to 7 October, 2015. It brought together academia and industry from around the world in an open dialogue, to discuss the latest innovations as well as develop possible strategies and new collaborations for a more sustainable way of using our resources.

The diverse and dynamic group of speakers provided in-depth insight, as well as, methods and mechanisms that have worked on different types of bauxite residue of different countries.

There were a total of 47 presentations of which 3 keynote lectures, 29 oral presentations, and 15 poster presentations which were presented for the 135 participants from 27 countries around the world.

The Panel Discussion session was the cherry on top, which at the end analysed, structured, directed and set out the ideas and material presented throughout the event, to head towards another rewarding and informative BR2018 Conference.

Sponsors were World Aluminium and Centre for Resource Recovery and Recycling Supporters were TMS and European Aluminium Association, while Media Partners were ICSOBA and AlCircle.

The Conference Dinner was held in the Grand Beguinage which is a UNESCO World Heritage part of the city. Here devout women lived, who for various reasons did not join a convent, formed communities on the fringes of the society. The oldest houses date back to 16th century and this part of the city have a unique atmosphere.

Who would like know more on BR 2015, one can watch a

Video: <http://conference2015.redmud.org>

Photos: [http://conference2015.redmud.org/?page\\_id=642](http://conference2015.redmud.org/?page_id=642)

Papers and presentations can be seen: [http://conference2015.redmud.org/?page\\_id=70](http://conference2015.redmud.org/?page_id=70)

(Based on the summary of Yiannis Pontikes at LinkedIn)



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## TECHNICAL PAPERS

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### Historic Developments and Trends in the Management and Use of Bauxite Residue

**Ken EVANS**

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#### Abstract

*The paper serves to briefly review the disposal and storage of bauxite residue from the late 19<sup>th</sup> century and early 20<sup>th</sup> century and discuss how the environmental aspects of disposal have changed. The paper further discusses the development of uses for bauxite residue over that period. In spite of over century of effort looking for uses, over 1,200 patents and hundreds of technically successful trials, less than 4 million tonnes of the nearly 140 million tonnes of bauxite residue produced annually is used in a productive way. A large proportion of material that is used, is in China and driven by government pressure. This paper also reviews the barriers and why the technical successes do not always translate into large scale uses. The most successful large scale uses are discussed and include cement production, raw material for iron and steel manufacture, manufacture of building materials, landfill capping, road construction and soil amelioration.*

#### Introduction

The paper serves as a brief overview of the history and trends in the management and use of bauxite residue, outlining: the dimensions of the problem; how methods of storage and disposal have developed over time and the implications for bauxite residue use; characteristics of bauxite residue; the technically successful uses; the challenges to implementation – real and perceived; a review of large scale/industrial scale successes; and some hopes for the future.

Annual production of smelter grade and chemical grade alumina in 2014 was some 108 million tonnes<sup>1</sup> which, with the exception of some plants in Russia, Iran and China, is all produced using the Bayer process. The global average for the production of bauxite residue per tonne of alumina is between 1 and 1.5 tonnes so it is estimated that some 130 to 140 million tonnes of bauxite residue is produced annually. This is generated at some 60 active Bayer plants. In addition there are at least another 50 closed legacy sites so the combined stockpile of bauxite residue at active and legacy sites is estimated at three thousand million tonnes.

#### History and trends in disposal and storage methods

Management of the storage of bauxite residue has evolved progressively over the decades<sup>2</sup>. In the early Bayer alumina plants, the residue generated was often merely piled up on site or an area adjoining the alumina plant. Occasionally nearby depleted mine or quarry sites, bauxite, shale or coal, were used. In other situations nearby estuaries or sea lagoons were used and then later as the closest

convenient areas were filled, valleys were dammed to contain the ever growing volume of residue. These methods of storage were especially true of the early European sites including: Bergheim (Germany) - on site storage then in a former lignite mines; Burntisland (UK) - disposal into an estuary, then behind a sea wall, see Figure 1, then old shale mine, see Figure 2; Gardanne (France) - storage in a dammed valley then disposal by pipeline to the sea; La Barasse (France) - storage on site then nearby dammed valley then disposal to sea via a pipeline; Larne (UK) - disposal into sea water lagoons; Ludwigshafen (Germany) - storage on site; Newport (UK) – disposal into estuary from barges then sea water lagoons; Salindres (France) – on site storage then in a dammed valley and Schwandorf (Germany) – on site storage.



**Figure 1 - Bauxite disposal into an estuary to recover land**



**Figure 2 – Bauxite residue disposal into a former oil shale mine**

Prior to 1980, most of the inventory of bauxite residue was stored in lagoon-type impoundments and the practice is still carried out at some facilities. In this method, the bauxite residue slurry from the mud washing circuit is pumped, with a solids content of 20 to 30%, into storage areas created by dams and other earthworks for secure containment. In many instances valleys were dammed for example, Ewarton (Jamaica), see Figures 3 and 4, Gardanne, Salindres, Saint Cyr (France), Ouro Preto (Brazil). Examples of old mine storage were: bauxite mines (Kirkvine (Jamaica), Bauxite (USA)), lignite mines (Bergheim), and oil shale quarries (Burntisland). In the case of sites constructed in the past three or four decades, the storage areas have normally been sealed to minimise leakage to the underlying ground and ground-water, however, this tended not to be the practice in earlier years. Sealing approaches cover a range of materials including compacted clay and/or the use of plastic and other membrane materials.

The supernatant liquor above the residue was normally returned to the plant for reuse thereby recovering some of the caustic soda value and avoiding contaminating the environment. Various drainage and seepage collection systems have been incorporated into the design and construction of the facilities. The construction of the storage area was often dictated by the type of bauxite residue and differed for clay like muds compared to more sandy residues. At Gramercy (USA), sand-bed filtration was used and “French Drains” were used with drainage pipes and covering layers of sand of different size and gravel to give permeability through the base of the lake. This was termed the DREW (Decantation, Drainage and Evaporation of Water) system.

There are many examples of this storage method but they include Stade (Germany), Burnside (USA) and Vaudreuil (Canada). In some cases low dykes or levees were built to the final expected height at the start and a new area constructed when more volume was required whilst in others the dam walls were successively increased when the space was filled. The area of suitable land readily available dictated the approach.



**Figure 3 – Bauxite residue disposal into a dammed valley to create a lagoon, early stages**



**Figure 4 – Bauxite residue disposal into dammed valley, later stages**

If the residue material is not neutralised before discharge to the storage lagoon, it becomes a highly alkaline, poorly compacted mud area covered by a highly alkaline lake, see for example the lake in Figure 4 which had a pH >12 and a soda level in excess of 2,000 mg/L many years after pumping had stopped. This creates safety and environmental hazards including the potential for contact of humans and wildlife with alkaline liquor and mud, and contamination of surface and ground waters by leaching of caustic liquor and other contaminants. Regrettably in many cases these early ponds have proved of limited efficacy and caustic liquor, plus other contaminants, has subsequently seeped into the surrounding environment. Ongoing remediation of these situations is proving to be a costly exercise. Addressing the risk and to eliminate the potential for catastrophic failure of the dam/impoundment and consequent environmental hazard to the surrounding area/communities introduces high monitoring, maintenance and remediation costs. Under some circumstances, this has created the prospect of an indefinite legacy.

Another disposal technique adopted by some plants was sea or river disposal particularly in the 1940s to 1960s. In at least six plants, two located in France (Gardanne and La Barasse), one in Greece (Distomon) and three in Japan (Shimizu, Ehime, Yokohama), bauxite residue was discharged into the sea either via pipelines or from ocean going vessels. Other alumina plants disposed of the residue into rivers or estuaries, for example into the Mississippi River (Gramercy), and Severn Estuary (Newport). In other cases in Ireland (Larne), Wales (Newport) and Scotland (Burntisland), land was reclaimed from the sea by disposing of the residue in tidal lagoons or behind sea walls. River discharge is no longer undertaken at any alumina refining facilities and all sea discharge will be completely phased out by the end of 2015.

As land for lagoon storage became scarce for many plants, “Dry stacking” methods were used. A dry stacking regime was adopted nearly 75 years ago in the UK<sup>3</sup> and about 50 years ago in Germany<sup>4</sup> and since the 1980s the trend has been increasingly towards dry stacking to reduce the potential for leakage of caustic liquor to the surrounding environment, reduce the land area required, and maximise the recoveries of soda and alumina. Considerable work was undertaken in Jamaica on the Robinsky<sup>5</sup> sloped thickened tailing disposal system and Ewarton adopted the practice in the mid-1980s<sup>6</sup>. See Figure 5. Additionally, improved methods for thickening and washing of the residues prior to storage,

and recovery of decant water during storage, have been developed to increase the recovery of valuable soda and alumina to the Bayer process plants and to minimise the potential for leakage to the surrounding environment.



**Figure 5 – Mud dewatering and compaction**

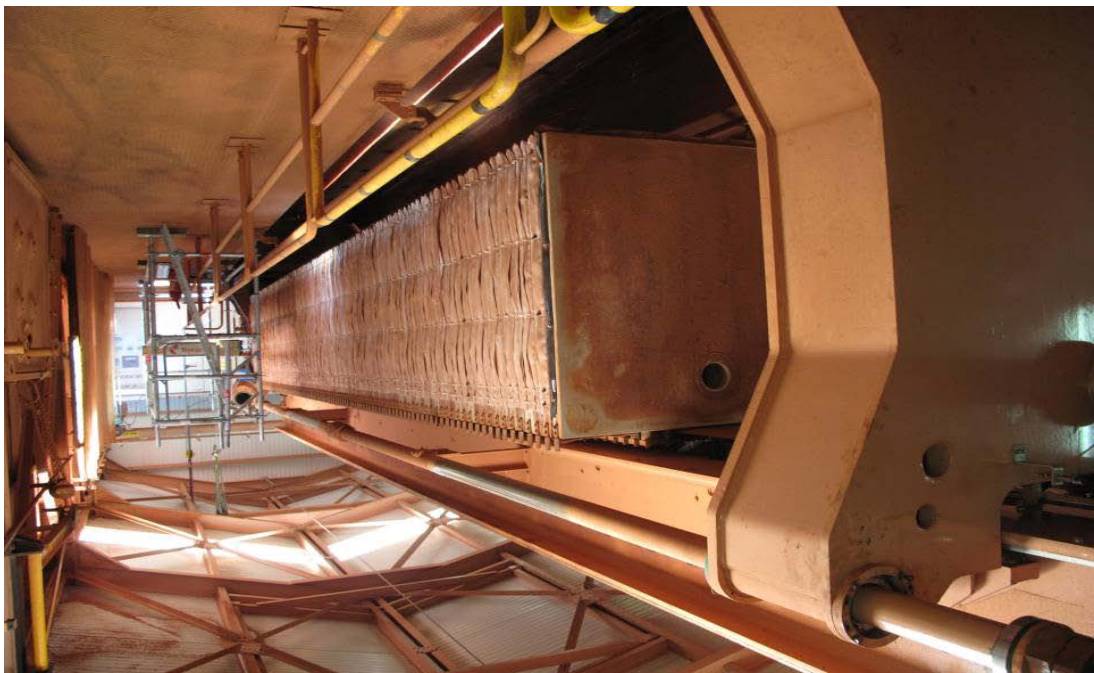
The current trend in residue storage practice is towards increasing use of dry stacking as the preferred technology, and further research to optimise this technology is appropriate. Very many plants now use equipment such as Amphirolos to aid dewatering of the mud in order to compact and consolidate the residue, see Figure 6. Partial neutralisation using seawater is practiced at a number of Australian plants close to the sea (Yarwun and QAL); carbonation by using waste carbon dioxide from ammonia production has been used (Kwinana (Australia)); and accelerated carbonation using intensive farming methods, Aughinish (Ireland), Kwinana, Worsley (Australia) is showing considerable benefits.

Filtration using drum filters and plate and frame filter presses to recover caustic soda, produce a lower moisture and more handleable bauxite residue have been employed for some 80 years but is now growing in usage. Plate and frame filter presses were adopted in Vaudreuil in 1936 when the plant was constructed and in Burntisland in 1941 as the lagoons adjacent to the site were full. In the case of Burntisland the bauxite residue needed to be transported on public roads through the town to a nearby old oil shale mine so a high solids content mud was a key requirement. In the mid 1960s at Ludwigshafen, vacuum drum filters were adopted. Figure 7 shows a typical press filter.

In addition to helping recover more caustic, this trend opens up considerable benefits in terms of reuse as the material is normally produced as a friable cake, with typically less than 28% moisture, and lower soda thereby dramatically reducing transport issues and costs. Alunorte (Brazil), Distomon (Greece), Gardanne, Kwinana, Seydisehir (Turkey) and many plants in China have already adopted or plan to adopt plate and frame filter presses. Hyper Baric filters are reported to achieve particularly low moisture content material with the performance of the press being enhanced when steam is used; moisture contents lower than 25% have been reported.



**Figure 6 – Dry mud stacking**



**Figure 7 – Plate and filter press**

The appalling and tragic incident at the bauxite residue ponds adjacent to the Ajka alumina refinery in Hungary in October 2010 when some 600,000 to 800,000 m<sup>3</sup> of caustic red mud slurry inundated the village of Kolontar and flowed into the Torna Creek, Marcal and Raba rivers had a significant effect on the alumina industry. The producers, via organisations such as the European Aluminium and International Aluminium Institute, have since worked collaboratively to look for improved solutions and propose best practice guidelines which were published in a guideline document<sup>1</sup>. The IAI

continues to encourage collaborative effort on improving storage, monitoring, safety standards, looking at improved remediation techniques and reuse opportunities. In 2011 the International Aluminium Institute issued a set of targets for IAI members to work towards<sup>2</sup>. Key messages coming out of the best practice reviews have been the drive to dispose of and store bauxite residue in a safer way with lower caustic and higher solids content. These moves will encourage the utilisation of residue as the material produced will be in a more acceptable form for transport, handling and reuse.

The changes within the industry over the last 20 years has meant that many of the relatively small Bayer plants have ceased operation and there has been an inexorable shift to much larger alumina refineries in countries such as Australia, Brazil and India. In a number of cases, the former alumina plant has been converted to a specialty alumina plant which uses aluminium hydroxide as feed instead of bauxite; this trend has been particularly apparent in Europe and includes Ajka, Bergheim, Ludwigshafen, Salindres and Schwandorf. In the USA the two former Bayer plants at Bauxite have closed but the specialty alumina operation at the former Alcoa plant continues in operation.

Reuse of bauxite residue has for long featured in the thinking of Bayer plant operators but in spite of over a century of endeavour and trials, only some 2 to 3% of the nearly 140 million tonnes of bauxite residue produced annually is used in a productive way. Thousands of trials have been successfully completed and dozens of uses have been identified as being technically feasible but the challenge remains to find good economically viable uses for the amount generated every year let alone eat into the material already stockpiled.

The bauxite residue disposal costs for a plant are obviously very dependent on the availability of a suitable disposal site, the distance from the plant to the disposal area and the method of conveying used (by pumping, conveyor or truck). It should be noted that pumping over long distances can be achieved, even in excess of 50 km. Residues from different bauxites also behave quite differently in terms of composition, mineralogy and particle size. They will have different handling and pumping characteristics and display widely different settling and particle packing characteristics thereby influencing moisture contents after treatment and handling costs. The variation in composition naturally has an overriding effect on potential applications so any practical work looking at applications must take into account the specific chemical composition, mineralogy, pH, particle size distribution, morphology and nature of the residue emanating from a particular plant.

There is relatively little published data on the cost of disposal of bauxite residue but it is generally estimated to be between 1 and 3% of the total production cost, perhaps US\$4 to 12. This is lower than often expected and must be borne in mind when potential uses are considered. In the absence of landfill taxes, which for example were introduced on bauxite residue in the UK in 1996, most companies have been reluctant to spend more than is required to comply with the law and ensure storage is undertaken safely in a manner that does not pollute the surrounding environment and the area can subsequently be restored. Despite the strong desire and enthusiasm of companies to present a 'green' and 'sustainable' corporate image, the utilisation opportunity must make economic sense, or at least close to, for projects to be implemented. Corporate attitudes have changed dramatically over the past 10 years, reflecting growing community awareness and to meet the demands of concerned shareholders and NGOs, and producers now have a more holistic attitude to resolving the problem and reducing the area given over to residual disposal areas.

Despite the increasing trend to higher solids contents and lower soda values, one retrograde factor with respect to generation of bauxite residue is the current diminishing stocks of high quality, easily extractable, high alumina bauxite sources – this has the effect of driving up the amount of residue produced per tonne of alumina produced.

### **Bauxite residue characteristics**

The key first steps in discussing uses is a consideration of the chemical compounds present in the bauxite residue, the levels present and the physical characteristics of the material. As discussed, the variation in composition is extremely wide as shown in Table 1; these are for commonly used bauxites and the range can be even broader for some unusual bauxites.

A wide range of other components may also be present at low levels; these will invariably be as metallic oxides e.g. arsenic, beryllium, cadmium, chromium, copper, gallium, lead, manganese, mercury, nickel, potassium, scandium, thorium, uranium, vanadium, zinc, zirconium and rare earth elements. Non-metallic elements that may occur in the bauxite residue are phosphorus, carbon and sulfur.

**Table 1: Chemical composition, expressed as oxides, commonly found in bauxite residue**

<b>Component</b>	<b>Typical range (%)</b>
<b>Fe<sub>2</sub>O<sub>3</sub></b>	<b>5 - 60</b>
<b>Al<sub>2</sub>O<sub>3</sub></b>	<b>5 - 30</b>
<b>TiO<sub>2</sub></b>	<b>0.3 -15</b>
<b>CaO</b>	<b>2 - 14</b>
<b>SiO<sub>2</sub></b>	<b>3 - 50</b>
<b>Na<sub>2</sub>O</b>	<b>1 - 10</b>
<b>LOM</b>	<b>5 - 20</b>

The minerals present are complex and comprise some which are present in the bauxite and others that are produced during the autoclaving and the desilication processes. The range of minerals typically found for bauxite residues is shown in Table 2.



**Table 2: Typical range of components found in bauxite residues.**

<b>Component</b>	<b>Typical range (%)</b>
<b>Sodalite (<math>3\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot \text{Na}_2\text{SO}_4</math>)</b>	<b>4 - 40</b>
<b>Al -goethite (<math>(\text{Fe},\text{Al})_2\text{O}_3 \cdot n\text{H}_2\text{O}</math>)</b>	<b>1 - 55</b>
<b>Haematite (<math>\text{Fe}_2\text{O}_3</math>)</b>	<b>10 - 30</b>
<b>Magnetite (<math>\text{Fe}_3\text{O}_4</math>)</b>	<b>0 - 8</b>
<b>Silica (<math>\text{SiO}_2</math>) crystalline and amorphous</b>	<b>3 - 20</b>
<b>Calcium aluminate (<math>3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}</math>)</b>	<b>2 - 20</b>
<b>Boehmite (<math>\text{AlOOH}</math>)</b>	<b>0 - 20</b>
<b>Titanium dioxide (<math>\text{TiO}_2</math>) anatase and rutile</b>	<b>2 - 15</b>
<b>Muscovite (<math>\text{K}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 2\text{H}_2\text{O}</math>)</b>	<b>0 - 15</b>
<b>Calcite (<math>\text{CaCO}_3</math>)</b>	<b>2 - 20</b>
<b>Kaolinite (<math>\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}</math>)</b>	<b>0 - 5</b>
<b>Gibbsite (<math>\text{Al}(\text{OH})_3</math>)</b>	<b>0 - 5</b>
<b>Perovskite (<math>\text{CaTiO}_3</math>)</b>	<b>0 - 12</b>
<b>Cancrinite (<math>\text{Na}_6[\text{Al}_6\text{Si}_6\text{O}_{24}] \cdot 2\text{CaCO}_3</math>)</b>	<b>0 - 50</b>
<b>Diaspore (<math>\text{AlOOH}</math>)</b>	<b>0 - 5</b>

In addition there are various other minerals sometimes found at low levels including Brookite, Calcite, Carnegieite, Chantalite, Dolomite, Hydrogarnet, Hydroxycancrinite, Katoite-Si, Lawsonite, Nepheline, Nosean, Portlandite, Schaeferite, sodium titanate, and zircon.

Sodium is the only element not found in the bauxite itself; some of the elements are soluble in the Bayer process and either build up in the Bayer liquor, or precipitate along with the aluminium hydroxide. Depending on the temperature used in the extraction process, some elements will increase in concentration in the bauxite residue relative to the bauxite, whilst others will be lower in the bauxite residue. Other than caustic soda, lime is normally the only other inorganic compound introduced during the Bayer process.

A wide variety of organic compounds can also be present, these are derived from vegetable and organic matter in the bauxite/overburden or the use of crystal growth modifiers or flocculants and includes carbohydrates, alcohols, phenols, and the sodium salts of polybasic and hydroxyacids such as humic, fulvic, succinic, acetic or oxalic acids.

In addition, the bauxite residue will contain small quantities of some of the soluble sodium compounds resulting from the sodium hydroxide used in the extraction process will remain depending on the dewatering and washing systems used. All alumina refineries try to maximise the recovery of the valuable caustic soda from the residues in order to reuse it during the extraction process. The residual soluble sodium species, predominantly a mixture of sodium aluminate and sodium carbonate, give rise to an elevated pH for bauxite residue slurries. Over time the residual sodium species are partially neutralised by carbon dioxide from the air to form sodium carbonate and other metal carbonate species; these species will result in a lower pH for the bauxite residue which renders them less hazardous.

The other factors that are important when considering uses are the physical characteristics such as particle size distribution and some variable parameters such as moisture content. The median particle size is normally in the range of 5 to 10  $\mu\text{m}$ , however, the breadth of particles is both very broad ranging from coarse sandy grains about 1 mm in size down to sub-micron particles for bauxite residues produced from different alumina plants and different bauxites;. Some alumina refineries separate the different size fractions during processing whilst others do not; the coarse sandy fraction has been given various names, for example “Red Sand<sup>TM</sup>” or “Red Oxide Sand”.

It should be noted that bauxite residue or red mud has been called a variety of names by different companies, sometimes after additional treatment and some of the names are registered trademarks: Bauxaline®, Alkaloam<sup>TM</sup>, Red Oxide Sand, Red Sand<sup>TM</sup>, Ferraloks, Bauxsol®, ReadyGrit<sup>TM</sup>, BPR – Bayer Process Residue, ARR – Alumina Refinery Residue, Bauxite tailings, Ferroalumina, Ferraloks, ART – Alumina refinery tailings, Redmedite, TerraB<sup>TM</sup>, ViroMine<sup>TM</sup>, ViroSoils<sup>TM</sup>, ViroSewage<sup>TM</sup>, Cajunite<sup>TM</sup> and RMG. Bauxite residue is arguably a more inclusive name as some alumina refineries separate the coarse high silica sandy fraction from the fine muds; some of the muds are brown rather than red; and some diasporic derived residues are almost black in colour. However, the name “red mud” tends to be more commonly used in North America and Europe.

### Technical successes in the use of bauxite residue

Many potential applications have been considered and explored for decades focusing on the elements present in the bauxite residue. Even Bayer himself in his 1892 patent describing the Bayer Process proposed the potential for iron recovery.

Possible applications can broadly be broken down into various categories:

- recovery of specific components present in the bauxite residue, e.g. iron, titanium, rare earth elements;
- use as a major component in manufacture of another product, e.g. cement;
- use of the bauxite residue as a component in a building or construction material, e.g. concrete, tiles, bricks;
- soil amelioration or capping;
- conversion of the bauxite residue to a useful material by modifying the compounds present, e.g. Virotec process.

The list of areas where bauxite residue covers almost all of inorganic material science and a full review would extend to pages, some of the most attractive have been: cement manufacture, use in

concrete, iron recovery, titanium recovery, use in building panels, bricks, foamed insulating bricks, tiles, soil amelioration, refuse tip capping/site restoration, treatment of acid mine drainage, soil amelioration, road construction, dam/levee construction, pigments, glass ceramics. Meanwhile some other uses which have been shown to be technically feasible but not yet exploited to any significant degree are: lanthanides (rare earth elements) recovery, scandium recovery, gallium recovery, vanadium recovery, cobalt recovery, yttrium recovery, adsorbent of heavy metals, dyes, phosphates, fluoride, water treatment chemical, ceramics, foamed glass, oil drilling or gas extraction proppants, gravel/railway ballast, calcium and silicon fertiliser, filler for PVC, wood substitute, geopolymers, catalysts, plasma spray coating of aluminium and copper, manufacture of aluminium titanate-Mullite composites for high temperature resistant coatings, composites with epoxides, composites with poly aniline, manufacture of radiopaque materials for the construction of X-Ray diagnostic and CT scanner rooms, desulfurisation of flue gas, arsenic removal, chromium removal<sup>7,8</sup>. Some applications, such as use in pigments have been successful but use very small tonnages.

The question so often asked is why some of these potentially exciting applications have failed to be implemented when on a small scale they look so attractive. It is certainly not the desire of producers to harbour their bauxite residue!

### Major barriers to reuse

When considering the commercial/industrial implementation of uses that have been found to be technically successful, it is important to consider the barriers that have prevented the implementation of apparently sound and economic solutions. The materials that bauxite residue would be replacing in any application are very often readily and cheaply available so any negative feature or minor impediment is potential barrier to change. Assessing both the actual risk, and the perceived risk to the stakeholders for any particular application is crucial. Some important risk factors to consider are discussed below.

#### Leaching of heavy metals

The leaching of metals, especially heavy metals, into the environment is a particular issue for any material that is used in building products, bricks, roads, in construction, soil capping or soil amelioration. Soluble chromium is normally the element of most concern though arsenic can also be a problem for some specific residues. This is generally only a particular issue when the materials are exposed to high or low pH values. Solubility/extraction tests of components or aggregates (for example EN 12457 – Waste Acceptance Criteria Testing) or metal uptake studies in vegetation may all be necessary depending on the application in order to show that the bauxite residue will not be a problem in use.

Possible concerns over liability of contaminating surrounding land may be a particular concern if the product is used in some way where the leachate from the structure etc. could leach into a water course.

#### Radioactivity

Most bauxites will contain low levels of radioactive elements, termed NORM (naturally occurring radioactivity material) in particular <sup>238</sup>U and <sup>232</sup>Th, and this is normally doubled in the bauxite residue. The radioactivity in the bauxite residue is sometimes referred to as TENORM (technologically enhanced naturally occurring radioactivity material).

In general two approaches are used to assess the risk from radioactivity: measurement of the elements that could lead to radioactivity, namely analysing for Ac, At, Bi, Pa, Pb, Po, Ra, Th, Tl, U and then calculating a radioactivity value; or by direct measurement. The EU Radiation Protection Guideline 112 has a recommended range of 0.3 – 1 mSv/y for building materials; the particular limit being determined by the expected exposure.

The data published on radioactivity levels has historically been low but some information that has been reported on a range of bauxite residue shows that thorium was only present in significant levels in bauxite residue from Venezuelan bauxite but still remains below acceptable limits. The uranium content is over 10 mg/kg in Jamaican and Venezuelan bauxites but the total radioactivity calculated will still remain below legislative limits in bauxite residue. Some of the uranium does dissolve in the Bayer process but it subsequently re-precipitates and is associated with the coarser bauxite residue fraction. Meanwhile thorium is not affected by low temperature extraction process and is most often associated with the fine bauxite residue fraction. Data for Australian derived bauxite residue shows a level of 0.005 – 0.2 Bq/g for the sand fraction and 0.15 – 0.6 Bq/g for the mud fraction due to  $^{238}\text{U}$  and 0.3 – 0.8 Bq/g for the sand fraction and 1– 1.9 Bq/g for the mud fraction due to  $^{232}\text{Th}$  and 0.07 – 0.23 Bq/g due to  $\text{K}^{40}$  in mud fraction<sup>9</sup>.

The IAEA (International Atomic Energy Authority) Basic Safety Guide for marketable materials sets a limit of 1 Bq/g per radionuclide; for uranium this is equivalent to 81 mg/kg. From the published data for bauxite residue, this level does not represent a problem for bauxite residues although it should be noted that the level measured for  $^{238}\text{U}$  and  $^{232}\text{Th}$  on bauxite residue from the closed Jamaican alumina plant at Moggetty was 0.97 and 0.32 Bq/g<sup>10</sup>. The values generally present in local soil for  $^{238}\text{U}$  and  $^{232}\text{Th}$  were 0.22 and 0.037 Bq/g respectively.

A thorough understanding of the radioactivity issues are most important when any application is considered. Public perception and concerns must be addressed as despite the data shown above, the radioactivity levels measured have stopped a number of interesting applications proceeding. Examples include the manufacture of bricks for domestic buildings in Jamaica, the use of construction materials in applications other than roof tiles in Hungary and the manufacture of ceramic insulating fibre for domestic situations. An “Activity Index” assessment has been proposed to consider each application on its merits looking at the level of radioactivity in the bauxite residue, the amount of bauxite residue in the product and the time and degree of expected exposure<sup>11</sup>.

### **Alkalinity/high sodium**

The high pH is a problem from both a health and safety aspect and potentially adverse effects in the particular application. This ranges from poor weathering resistance in construction materials to high sodicity when used in soil amelioration. Both high sodium levels and high pH will be reduced when press filters are used. Accelerating carbonation by the use of carbon dioxide, intensive farming or acid neutralisation as a first stage could also be considered to reduce the pH.

### **Hazardous rating of bauxite residue in some jurisdictions**

There have been many discussions, particularly in the EU, concerning the hazardous nature of bauxite residue in particular in respect of its pH. If classified as a hazardous waste, this will add considerably to the cost of all aspects of handling, storage and transport. Based on a number of standard test criteria, any waste material with a pH value above 11.5 is often considered hazardous. Implementation

of an improved filtering operation, may reduce the pH of bauxite residue to a level that avoids skin and eye irritation.

### **Moisture level**

A high moisture level will add to transport costs and will be an issue if energy has to be expended in driving it off in drying or firing (calcination), so it is advantageous for the bauxite residue to have as high a solids content as possible. Additives such as starch have been used for dewatering for very many decades but from the 1980s there was growing use of synthetic flocculants. The use of plate and frame press filters goes back a very long period and was certainly being used in the 1940s. It then seems to have fallen out of favour and rotary drum filters became more common. Now there is a trend back to the use plate and frame press filters being adopted to reduce water content which can yield a moisture level of 26/27% or lower.

### **Transport costs**

The logistics cost is very substantially increased if the material is classified as hazardous since special procedures must be implemented during transportation. Whilst the high alkalinity does not impose a problem with corrosion of steel, it does cause pitting of aluminium which is a part of the UN transport code. If the conversion or use is not carried out at the alumina refinery, the bauxite residue will almost certainly be competing with some other low cost ore, mineral or waste - reducing the transport costs to as low as possible is therefore essential. All mitigating operations should be considered, e.g. pumping the bauxite residue to some other area and processing it, dewatering methods/aids, solar drying.

A major trend since the 1980s has been the closure of small and medium size alumina plants, perhaps 100,000 to 300,000 t/y annual production, in Europe and the growth of much larger plants, this is especially true in Brazil and Australia. The largest ones can produce over 6 million tonnes per year of alumina. These larger plants are very often remote from large centres of population which is likely to mean there is a lower level of industrial activity and consequently limit some opportunities for the use of bauxite residue. This makes the transport cost issue even more critical when considering uses.

### **Industrial scale successes**

It is generally estimated that some 2 to 3.5 million tonnes of the bauxite residue produced annually is used in some way although reliable data is difficult to obtain as it does fluctuate markedly from year to year as the economics change.

#### **Current estimates from various sources are:**

- Cement – 500,000 to 1,500,000 tonnes;
- Raw material/additive in iron and steel production – 400,000 to 1,500,000 tonnes;
- Roads (see Figure 8)/landfill capping (see Figure 9)/soil amelioration – 200,000 to 500,000 tonnes;
- Construction materials (bricks (see Figure 10), tiles, ceramics etc.) – 100,000 to 300,000 tonnes;
- Other (refractory, adsorbent, acid mine drainage (Virotec), catalyst etc.) – 100,000 tonnes.



**Figure 8 – Use of Red Sand™ for road construction (Photograph courtesy of Alcoa)**



**Figure 9 – Use of Bauxaline® in landfill capping in Provence**

Bauxite residue can provide valuable iron and alumina values in the production of Ordinary Portland cement. Excluding China, the use of bauxite residue in the cement industry in the manufacture of clinker is estimated at approximately 260,000 t/y almost all of which is from the Nikolayev alumina plant in the Ukraine. The bauxite residue from Nikolayev is used in cement plants in the Ukraine, Russia, Georgia, Moldova and Belarus. The Nikolayev refinery blends the residue produced to give the cement plant a consistent feed and the climate allows a reasonably low moisture product to be produced. There is modest usage of bauxite residue from AdG's plant in Distomon in cement production at a plant in Patras; further usage is restricted by the lack of dry storage. Much larger usage, up to 180,000 t/y was anticipated at a cement plant in Milaki but changing economic

circumstances have put increased usage on hold. There has also been some historical usage of bauxite residue from the refinery in Tulcea in a local Romanian cement plant and also reportedly small scale usage of bauxite residue from the Gandja alumina refinery in Azerbaijan in cement. The use of bauxite residue in cement in China was formerly several million tonnes a year but this has fallen because of the changes in construction industry standards and also a reduction in the number of plants operating a sinter or Bayer-sinter extraction route. It should be noted that the bauxite residue produced from the sinter or Bayer-sinter extraction route is very different chemically from that produced in a conventional Bayer alumina plant.



**Figure 10 – Use of bauxite residue in bricks, JBI, Jamaica**

The usage of bauxite residue in steel manufacture is of the order of 70,000 to 100,000 tonne/year, excluding China. The iron ores that are normally used in iron and steel manufacture have an iron content of typically 55 to 70% with 66% being available from many good quality sources. Meanwhile for comparison, bauxite residues have a typical range of iron of 3 to 42%. It is important to consider these contents and realise the difficulty in even closely matching the economics against using virgin iron ore, especially at the current price of iron ore. Some success has been achieved in China, particularly in plants in Southern China where the bauxite residue can have an iron content of up to 42%. Notably success has also been achieved using magnetic separation techniques as a first stage of processing to concentrate the iron fraction. The bauxite residue material is also wet and has a high sodium content which is a disadvantage in steel production.

The simultaneous recovery of other metals, for example titanium and aluminium, would improve the economics of using bauxite residue for iron recovery in steel production. The only non-Chinese plant using bauxite residue for making steel is based in the Urals. The work on iron extraction from bauxite residue in the Southern Chinese alumina plants is discussed later. Several Indian sources of bauxite residue are relatively high in iron, between 30 to 39%, and a considerable amount of work has been done to recover the iron values in the bauxite residue from the NALCO plant using the Romelt process but whilst technically feasible, it was uneconomic because of the high energy costs involved in the process.

China is worth discussing separately as it devoting a very considerable effort into searching for and implementing reuse of bauxite residue, much of it being driven by Chinese Government initiatives<sup>8</sup>. China has shown the most dramatic change in the last 10 years with alumina production increasing from about 2.5 million tonnes in 2000 to over 50 million tonnes by 2014<sup>1</sup>. The generation of bauxite residue has grown to over 50 million tonnes a year, the alumina manufacturing routes have traditionally been very different because of the nature of the indigenous bauxite. Sinter routes or combined Bayer-sinter routes were widespread but are now declining sharply and the industry has become more dependent on imported bauxites. This change in route has significantly changed the characteristics and composition of the bauxite residues being produced. Hitherto much of the imported bauxite was from Indonesia and Australia but curtailment of bauxite exports from Indonesia is changing the nature of the bauxite residue yet again. Traditionally the alumina plants in the Northern part of China produced a residue very high in calcium and silicon oxides but low in iron oxide making them suitable for cement production whilst those in the south of China have a residue high in iron which makes the recovery of iron the most likely option for them to pursue. A very strong driving force in China has been government imposed legislation requiring that bauxite residue is reused.

The manufacture of bricks, tiles and other building materials has been shown to be technically possible by many groups of workers from a wide variety of sources of bauxite residue using both fired and chemically bonded methods. Outside China, however, whilst plants have started up, production has not continued.

Use of bauxite residue for capping municipal landfills is carried out in France; the amount varies considerably from year to year but is estimated at 40,000 to 100,000 tonne/year. It can only be undertaken within a relatively small radius of each refinery depending on local transport costs and the availability of other covering/capping materials; the maximum distance that the residue can effectively be transported for this application is estimated to be about 75 km. Municipalities will normally wait until an entire site is full before remediating/capping it, hence the wide variation in usage between years. The bauxite residue must be in a form that can readily be carried in trucks on public roads. Possible concerns are dust from the bauxite residue when dry and heavy metal leaching characteristics.

Somewhat related, has been the use as a soil amendment/conditioner for acidic/sandy soils; on large scale trials this has been shown to be safe and beneficial, especially in controlling high levels of phosphorous. Controversy over two decades has prevented its implementation until now.

Usage for road building and dyke/levee construction is estimated at 20,000 tonne/year, however, some is used internally within each alumina site complex, often for roads within the bauxite disposal area. A considerable amount of work has been done in Western Australia by Alcoa in conjunction with Curtin University on using Red Sand™ in the construction of roads<sup>12</sup>. In this process, the coarse sandy fraction of the bauxite residue is neutralised with carbon dioxide to create the Red Sand™.

Soil amelioration of acidic and sandy soils offers considerable opportunities although current usage is limited and spasmodic.

## Summary

The early history of bauxite residue storage involved using estuaries or land impoundment areas adjacent to the factory as a low solids slurry. Disposal into rivers, estuaries or the sea became



common was common for a number of years but this has now ceased. Storage of bauxite residue as a dilute slurry in old mines, impounded areas or dammed valleys was widely practised until the mid-1980s but since then there has been a growing trend to higher solids storage method. More recently, filter presses to produce an even higher solids residue have become increasingly common. In many ways it is discouraging that despite so much work over the last century only some 2 to 3% of the 140 million tonnes of bauxite residue produced annually is used in a productive way. Some of the applications have been economically beneficial for a number of years and then factors have changed which renders them no longer economically viable. However, it is vital to consider how changes in process technology or demand requirements over time means that ideas previously considered not worth exploiting can become viable and commercially attractive. From the process side, improvements include: the increasing use of press filters will give residues with lower moisture levels, lower soda levels, lower contaminants, lower pH levels; the higher efficiency electro-magnets that are now available allows for more effective iron recovery from bauxite residue. Meanwhile the growing demand for scandium in aluminium alloys or the demand for particular rare earth elements also present new opportunities. In addition, public, corporate and government attitudes have never presented such an encouraging environment for developing and implementing bauxite residue uses.

### Acknowledgements

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## Karl Josef Bayer (1847-1904)

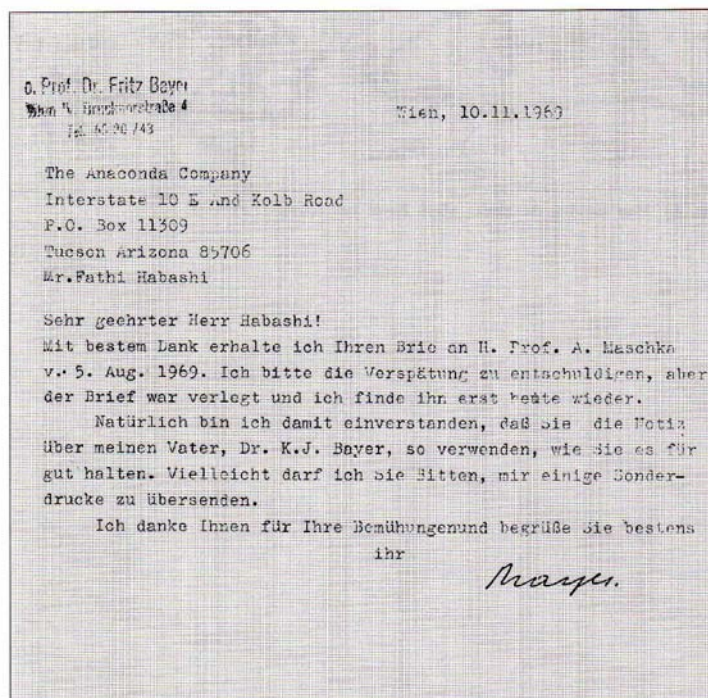
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### INTRODUCTION

In 1969 while the writer was working at Anaconda's Research Department in Tucson, Arizona, an old Austrian friend, Professor Franz Pawlek (1903-1994) who had just retired from the Technische Universität in Berlin visited him. When the writer raised that there was practically nothing written about Karl Josef Bayer in historical metallurgy books, or books on aluminum either old or new, although he was so famous for his process for manufacturing alumina, he was told that he knew only that Bayer had died a poor man, and that he was Austrian and not German. The writer then took the matter to the Austrian Chemical Society in Vienna and through the efforts of its secretary, Professor Anton Maschka (1914-2002) whom the writer knew well, he was able to get the home address of Professor Fritz Bayer, the inventor's son.



**Figure 1- Letter from Prof. Fritz Bayer dated November 10, 1969**

Professor Fritz Bayer (1900-1984) was the writer's examiner in electrochemistry at the Technische Hochschule in Vienna (now known as Technische Universität) when he was a graduate student there from 1956 to 1959. Fritz Bayer retired from teaching at the age of 70 in 1959, the same year the writer graduated. He was kind enough to send the writer a comprehensive biography of his father and a photograph. Figure 1 shows the letter from Prof. Fritz Bayer dated November 10, 1969. The writer immediately sent the photograph to be included in Volume Two of his book *Principles of Extractive Metallurgy* which was at that time (1969) in press. Later, a summary of the biographical data was

published few years later in Volume One of the newly founded series *Progress in Extractive Metallurgy* in 1973. This included also other photographs of Bayer that were kindly supplied to the writer by another old Austrian friend from Leoben, Professor Erich Schwarz von Bergkampff who retired from teaching at the Montanistische Hochschule (now Montan Universität) in 1962. The article in *Progress* included the German text of the two patents by Bayer.

## BAYER AS A YOUNG MAN

Bayer was born in Bielitz few kilometers south west of Cracow (Kraków) in Silesia, at that time a Province of the Austrian Empire, now in Poland. The map of Europe at that time was quite different from what we know it today. It was the age of great empires: the British, French, German, Russian, Ottoman, and Austrian empires.

Bayer went to school at his home town and at the wish of his father, who was an architect, started to study architecture (Figure 2). Later he switched over to science and went to Wiesbaden in Germany to work in the Laboratories of the famous analytical chemist Remigius Fresenius (1818-1897) then in a steel factory in Charlevoix, Belgium. Finally he went to Heidelberg to study chemistry at the University of Heidelberg. In Heidelberg, Bayer worked under Professor Robert Bunsen (1811-1879) for three years. At that time Bunsen's laboratory was visited by many chemists who became famous later on. Among those was Dimitri Mendeleev, Friedrich Beilstein, Henry Roscoe, Auer von Welsbach, Lothar Meyer, Victor Meyer, and many others. Bunsen's reputation stems from his discovery, together with the physicist Gustav Kirchhoff, of the spectroscopic method of analysis, and the discovery of the two metals rubidium and cesium by this new tool. Bunsen is also famous for the burner known by his name and now found in every chemical laboratory.



Figure 2- Bayer as a young man

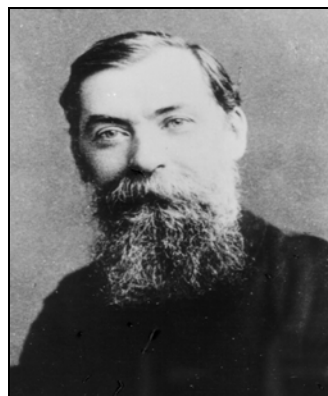
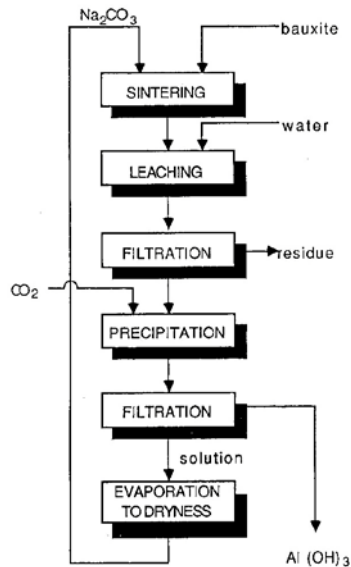


Figure 4- Bayer in Saint Petersburg

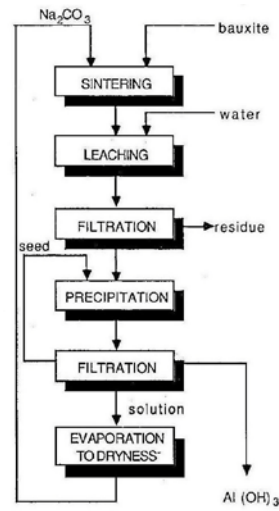
In Heidelberg, Bayer got the doctorate in 1871 on the properties of indium which was discovered few years earlier, in 1863 in Germany. The front cover of the document (Figure 3) shows the name of Friedrich, Great Duke of Baden and Duke of Zähringen [where the University of Heidelberg is located], Karl Knies the Academic Vice Rector. This is then followed by the Dean, the senior professors and other professors without indicating their names. Indicated also the name of the university dedicated to Ruprecht Karl.



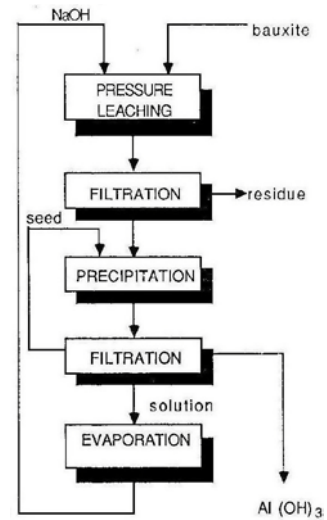
sulfate), then squeezed, dried and steamed where upon aluminum hydroxide is precipitated on the fibers. Thus treated, the textiles could be immersed in a dye solution to form a colored "lake". This was a standard method of dyeing at that time.



**Figure 5- Le Chatelier process for preparing aluminum hydroxide**



**Figure 6- Bayer's discovery for preparing aluminum hydroxide by seeding in 1888**



**Figure 7- Bayer's discovery of leaching bauxite under pressure in 1892**

While in Tentelev, Bayer at the age of 41 made the discovery in 1888 that aluminum hydroxide could be precipitated from sodium aluminate solution if a seed of a freshly precipitated aluminum hydroxide were agitated vigorously in the cold solution (Figure 6). The product was pure and can be easily filtered and washed. The process was soon adopted by the Tentelev Plant. Four years later in 1892 he made his second discovery that alumina contained in bauxite could be dissolved selectively by heating with a solution of sodium hydroxide under pressure in an autoclave to form sodium aluminate solution (Figure 7). He found also that the alkaline mother liquor obtained after the precipitation of aluminum hydroxide could be used.

At the age of 45 after well establishing his professional career and his social status, Bayer got married to the niece of the Russian statesman Count Sergei von Witte who was of German origin and who became briefly prime minister after the 1905 Revolution during the reign of the last Russian Tsar Nicolai II. After seven years in Saint Petersburg, Bayer then moved to another chemical plant at Yelabuga on Kama River 200 kilometers east of Kazan in the Tatar region not far from Ural Mountains to build the second plant for alumina manufacture by his process. Bayer stayed only two years in Yelabuga; during this period he received numerous contracts from foreign countries to build alumina factories. The aluminum industry in Russia started only many years after the revolution; bauxite was first mined there in 1926 at a location called Boksitogorsk which means bauxite city and is 150 kilometers east of Saint Petersburg. The first reduction plant was constructed in 1932 at Volkhov not far from the deposits.

## RETURN TO AUSTRIA

Bayer then returned to Austria with the intention to develop the aluminum industry in his country. He settled in Rietzdorf in southern Styria and devoted some time to scientific research. During this period he developed a method for the manufacture of synthetic cryolite. He then developed the first bauxite deposit in Austria and built a plant to produce  $Al_2O_3$  by his process. However, he was unable to raise enough capital, and thus his plans failed. Bayer was an average scientist but he was an inventor and had a great sense of enterprise. He published only one paper entitled, "Studies on the Winning of Pure Aluminum Oxide" but his patents were no doubt of great importance. He died suddenly at the age of 57; his widow died much later at the age of 94. Some foreign companies who were applying his patents stopped paying royalties after his death. It was difficult at that time to sue them, and consequently his house and laboratory had to pay for his debts.

In 1906, his family had to move to Graz. Bayer raised five sons and a daughter. His home in Rietzdorf was a meeting center for many famous industrialists among whom were Paul Héroult and Charles Hall the discoverers of the electrolytic process for aluminum production. He loved music and the arts; he himself was a talented artist. He spoke six languages: German, French, English, Russian, Italian, and Slovak. He had an excellent collection of minerals which he displayed at the Chicago exhibition in 1890.

Bayer is honored in his native country Austria by the medal bearing his name (Figure 8). It is awarded every six years to a distinguished researcher in the field of aluminum. The award ceremony takes place during the *International Light Metals Congress* which is held in Leoben and in Vienna. Bayer's first name appears as "Karl" in his patents but in the latinized form as "Carl" on his medal. He is also honored by an Austrian postage stamp issued in 1987 showing Bayer at an old age (Figure 9). The Hungarian aluminum industry also issued in 1987 a medal in Bayer's honor to commemorate the hundred year's anniversary of depositing his first patent (Figure 10).



**Figure 8- Austrian medal bearing Bayer's name. Courtesy Prof. Erich Schwarz-Bergkampff**



**Figure 9- An Austrian stamp issued in 1987 showing Bayer at an old age**



**Figure 10 Hungarian Bayer`s medal issued in 1987.**

Courtesy Prof. Zoltán Horváth, Miskolc University, Hungary

### SUGGESTED READINGS

F. Habashi, "Bayer's Process for Alumina Production. A Historical Perspective", *Cahiers d'histoire de l'aluminium* 13, 21-37(1993-94). A shortened version in *Bull. Hist. Chem.* (17/18) 15-19 (1995)

F. Habashi, "A Hundred Years of the Bayer Process for Alumina Production", *CIM Bull.* 80 (909), 70-76 (1988). Also in *Light Metals 1988* pp. 3-11, editor L.G. Boxall, TMS-AIME, Warrendale, PA 1988

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## ICSoba MATTERS

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### Formal Changes to ICSoba

There are some changes that were proposed to the members at the Members Meetings in Zhengzhou and Dubai and that were accepted. The changes result from the need to strengthen ICSoba and do everything possible to assure its continuity. More than a half century of contributions to society have proven ICSoba's cause.

One of the changes that were already implemented was the discontinuation of the Council. This body was judged ineffective. At one point in time, ICSoba had up to 30 Council members and too many of them did not contribute at all. ICSoba needs individuals who are willing to step-up and accomplish things. Also the Council Chair position disappeared and was replaced by the position of Program Director. In this new capacity, the Program Director assembles a team of active volunteers who are well positioned to build a conference program in 5 subjects: bauxite, alumina, carbon, electrolysis and aluminium (downstream). The capable volunteers become subject Chairmen and often with support from associates, contact potential contributors, gather abstracts, correct papers and assume their high editorial standard. The new model has already proven its value in Dubai, where subject Chairmen were highly visible and effectively organized their sessions.

The second major change involves the position of President. During the Zhengzhou conference in 2014, Frank Feret stepped down as President to facilitate a new ICSoba management structure. It was proposed that the President will come from the organization hosting the annual conference and will be elected annually. As in the past, the President is elected by the Board of Directors from among the active members. The President's role is to facilitate support by the host organization and to increase visibility of ICSoba. This represents a win/win situation for ICSoba and the host company. The host company can better promote its image and its interests. Equally, the individual that takes on the role of President can influence the conference program and is rewarded by global acknowledgement. The company's employees participate in the event in larger numbers and have access to ICSoba's unique forum.

The changes should strengthen ICSoba, facilitate its mission and assure continuity. As the 2015 ICSoba conference in Dubai was hosted by EGA, Ali Al Zarouni (Senior Vice President – Smelter Operations) was elected President for that year. In 2016, the ICSoba conference moves to Quebec where Rio Tinto agreed to become its host. Accordingly, the Board of Directors elected Claude Vanvoren - Vice President of Technology, R&D, Rio Tinto Limited to serve ICSoba as its President in 2016. Rio Tinto will also facilitate field trips to two of its plants in Saguenay, Quebec.

In terms of other changes, we regret to announce that Alex Gomes – Director of Technology at Votorantim, Brazil decided to step-down from the ICSoba Board of Directors due to new assignments within his company. Alex indicated Roberto Seno Junior, also Director of Technology at Votorantim as his replacement. The announcement was made at the conference in Dubai. The Board of Directors thanks Alex for his valuable contributions in the past and looks forward to working with Roberto going forward.

At present, Andrey Panov, Frank Feret and Michel Reverdy, who were elected by members in Zhengzhou, continue their work. Claude Vanvoren, Houshang Alamdari and B.S. Pani complement the new Board. The Directors will jointly assure responsibility for the organization and have assigned duties. Frank Feret will remain the external contact for ICSoba. György Bánvölgyi continues as the Newsletter editor and Dipa Chaudhuri remains the secretary. Composition of the new Board of Directors is given in the table below:



<b>Who</b>	<b>Association</b>	<b>Position</b>	<b>Email Address</b>
Claude Vanvoren	Rio Tinto	President	<a href="mailto:claudio.vanvoren@riotinto.com">claudio.vanvoren@riotinto.com</a>
Dr Frank Feret	ICSoba	Vice President, CEO	<a href="mailto:feretfr@gmail.com">feretfr@gmail.com</a>
Dr Andrey Panov	Rusal	Vice President Secretary General	<a href="mailto:Andrey.Panov@rusal.com">Andrey.Panov@rusal.com</a>
Michel Reverdy	Emirates Global Aluminium	Program Director	<a href="mailto:michel.reverdy@hotmail.fr">michel.reverdy@hotmail.fr</a>
Prof. Dr. Houshang Alamdari	Laval University	Director University Affairs	<a href="mailto:Houshang.Alamdari@gmn.ulaval.ca">Houshang.Alamdari@gmn.ulaval.ca</a>
Roberto Seno Junior	Votorantim	Regional Director South America, Australia	<a href="mailto:roberto.seno@vmetais.com.br">roberto.seno@vmetais.com.br</a>
B.S. Pani	SPAN Resources	Regional Director Asia	<a href="mailto:bspani@yahoo.com">bspani@yahoo.com</a>

Also, we would like to announce that the Board decided to offer free registration to future conferences for those past Board members who are retired or no longer have permanent work. Only the annual membership fee will apply. For other retirees, the reduced (student rate) will apply.

### **The Best Paper Award**

During the conference in Dubai, from among more than 100 submitted, several papers were selected for the best paper award. Re-launched this year, the awards are dedicated to recognizing outstanding papers across the entire program. Four subjects were considered: bauxite, alumina, carbon and electrolysis. The subject organizers of each stream: Roberto Seno Jr (bauxite), Steve Healy (alumina), Mathieu Arletaz (carbon) and Vinko Potocnik – Viktor Buzunov (electrolysis) made their selections. The awarded papers are:

1. Thomas Baumann for his paper: “AKW Apparate + Verfahren GmbH and its expertise in bauxite upgrading”
2. Roberto Seno Jr, Caio van Deursen, Rodrigo Moreno and Thiago Franco for their paper: “Votorantim Metais/CBA Bauxite Residue: Challenges and Solutions”
3. Tapan K. Sahu, Saleh A. Rabbaa, Amer Al Marzooki, Muhammad S. Malik, Bienvenue Ndjom, Pragasan Palavar and Esam Mohamed for their paper: “Strategy for sustaining anode quality amidst deteriorating coke quality”
4. Benedicte Allard, Arvind Kumar and Mohamed Tawfik for their paper: “Performances of green and eco-friendly ramming pastes in EGA pots”
5. Asbjørn Solheim, Henrik Gudbrandsen, Karen Sende Osen and Jannicke Kvello for their paper: “Current efficiency in laboratory aluminium cells”.

In addition to an award and public acknowledgement at the conference for the best paper, the authors will each be presented with an aluminium art sculpture. For the authors awarded in Dubai the sculptures will be waiting in Quebec. Starting in 2016 a special award will also be given to student authors. Moreover, one free registration for a future event will be drawn from among the names of the awarded authors that attend the Quebec conference. The public drawing will take place during the gala dinner.

## Letter from the Delegates

Gentlemen;

Thank you so much for the warm hospitality shown by the EGA group and the wonderful planning and execution of the conference by the ICSOBA group. My company had attended when it was held in Brazil but this was my first meeting to attend. I saw so many old friends and met so many new interesting people that it was hard to leave the venue. The papers were among the best I have participated in. I often wanted to be at two places at the same time. Congratulations for an excellent job for your industry. I look forward to next year in Quebec City. It is a beautiful place and I am sure we will have an exciting conference. The goals of sustainable aluminum productions are becoming more present and more attainable thru the work of all the scientist and engineers who attend functions like the ICSOBA.

Warm Regards;

*Dave*

David Roth

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Thank you and see you in Quebec City. This was definitely one of the better conferences on Bauxite and Alumina. You have outdone TMS.

Best regards,

**Errol Jaeger**

## ICSOBA Medals

On the occasion of ICSOBA's 50th anniversary in 2013, the Awards Committee decided to produce commemorative medals (see below). The new "ICSOBA Commemorative Medal" is 70 mm in diameter and takes its inspiration from two past designs. On one side are the embossed portraits of Pierre BERTHIER, Karl Joseph BAYER, Paul Louis Toussaint HEROULT and Charles Martin HALL. On the other side are the emblems of ICSOBA and the World, the full ICSOBA name, the name of the person awarded and the year of bestowal.



As in the past, the "ICSoba Commemorative Medal" constitutes a special recognition and may be awarded only to a small number of recipients each year. The medal may be awarded to those members who achieved significant scientific or practical results within the field of work, or who notably strengthened ICSoba organization or promoted its international scientific and industrial cooperation. The name of the awarded person is inscribed on the medal, and the awarding event is published in the NEWSLETTER.

Six medals were awarded in Krasnoyarsk (Dr György Komlóssy, Dimitri Contaroudas, Prof. Dr Peter Polyakov, Dr Viktor Buzunov, Dr Andrey Panov and Marja Brouwer). Last year in Zhengzhou four medals were awarded to: Roelof Den Hond (past president), Prof. Dr Li Wangxing, Dr Jeannette See and György Bánvölgyi.

This year three medals were awarded in Dubai. The first medal was awarded to **Dr Ali Al Zarouni** in recognition of his work as the 2015 ICSoba president, which includes welcoming ICSoba in Dubai, facilitating the organization of the highly successful conference, and seeing to ICSoba's prosperity and growth.

The second medal was awarded to **Michel Reverdy**, ICSoba-2015 Program Organizer, for his work on the Board of Directors and for outstanding contribution to organization of this year's conference.

The third medal was awarded to **Dr Vinko Potocnik** for his lifetime achievements as an accomplished scientist and educator in the field of aluminium electrolysis, and for his outstanding contribution to the organization of the 2015 ICSoba conference.

Since 2013 two medals are given each year to the visited plants as tokens of appreciation for hosting ICSoba delegates. This year the medals were awarded to Dubai Smelter and to EMAL smelter.

## Sponsors 2015

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## Associated Organizations

Red Mud  
**Red Mud Project**

Brazilian Aluminium Association ABAL



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## Public relations and Communication

### Promoting the participation of academicians in ICSOBA

#### **Professor Houshang Alamdari, PhD., Ing.**

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### Introduction

As per my personal observations and analysis of the past ICSOBA papers, it seems that the presence of Academia is not as high as it would be suitable for such an event. Although the papers and the presentations are of high quality, they are much more focused on the technico-economical and commercial aspects of the Al production process. An appreciable amount of papers deal with tool developments or process optimization. Very few papers however are dealing with fundamental aspects of the process, e.g. thermodynamics, new characterization techniques, modeling, or understanding of physical phenomena. This is comprehensible, since most of the participants are from the industry, either the producers or the suppliers. While, most of the fundamental works are usually performed by graduate students, which were quasi-absent, at least in Dubai. It is therefore important to increase students' participation in our event.

### What the academicians or the students expect from a conference?

Contrary to the industrial participants, who aim at promoting their technology or selling their products, an academician aims at sharing his/her research results with the potential end-users. Therefore, the paper itself becomes the product an academician wants to promote. The valorization of this paper is thus important for an academician.

Whether we agree or not, the value of the research results are quantified by the ranking of the journals or the proceedings in which they are presented. The students and the academicians are therefore dragged towards the highly ranked journals and conferences.

One of the indications of the quality for a journal or a conference proceeding is its impact factor. This factor is greatly influenced by the number of the citations a journal can achieve. Three factors influence the citation: the visibility of the paper, the general interest of the research community to the topic, and the quality and originality of the research work. When an original result is obtained, the students prefer to publish it in a journal with an established impact factor, rather than to present it in a conference without an impact factor. Thus, in order to attract the academia to ICSOBA, we have to get an impact factor. The higher this factor, the more attractive it would be.

### Best strategy to get an impact factor for ICSOBA papers

Most of the conference proceedings and many journals do not have an impact factor. As discussed in the last board meeting, the fact that "Travaux" becomes an open access document will certainly increase the visibility of the papers and their future citations. In addition, expanding the research topics to fundamental works will certainly increase the general interest of the research community to the topics published in ICSOBA. However, getting an impact factor for "Travaux", e.g. from "Thomson Reuters", would be a long way, taking probably several years or a decade.

Taking into the account the importance of the impact factor in attracting the academicians, it seems that the best strategy would be to associate ICSOBA with a journal having an established impact factor. This approach is not free of difficulties since most journals do not publish the results, if they have already been published or presented elsewhere. In addition, the journal owns the copyright of the results. One solution for this issue is to publish a “special issue” of a well-established open source journal, clearly specifying that the original papers had been published in ICSOBA-XX (XX stands for the year of the event). This way, the copyright issue is addressed since the “open source” journals do not own the copyright, so that the copyright could be retained either by ICSOBA or by the author.

Having this in mind, I discussed with the management board of “Metals”, an open access journal, to explore the idea of publishing a “special issue” of this journal which will be exclusively dedicated to publish the selected and high quality papers presented in ICSOBA-2015 conference. This journal recently got its first impact factor (IF: 0.089). The journal management board agrees with this approach and the special issue could be entitled as: Selected papers from "The International Committee for Study of Bauxite, Alumina& Aluminium 2015".

### Advantages of “Metals: special issue” for ICSOBA

Several advantages could be taken from associating ICSOBA with Metals journal.

1. The established impact factor of the journal could encourage the academicians and students to participate at ICSOBA and publish their work in both “Travaux” and “Metals: Special issue”.
2. “Metals” has a broad audience. A special issue of this journal, dedicated to ICSOBA papers, would be an effective advertisement for ICSOBA.
3. As the papers will be further peer reviewed by the journal, the quality of the papers will be further increased.

### Selection and publication process

The following steps are proposed for selection and publication of the special issue:

1. Each session chair selects about 5-6 best papers in his/her session.
2. A maximum of 25 papers are targeted in this step, having in mind that some papers will not be accepted by the journal.
3. On behalf of the journal, I contact the authors and inform them that their paper has been selected by ICSOBA to be published in a special issue of “Metals”.
4. The authors reformat their papers and submit them to the journal.
5. The journal proceeds for peer review of the papers.
6. The reviewers comment on the paper. In this step, the reviewers could “Accept” or “Reject” the paper. In most cases, they will ask for further clarifications/modifications or some additional data.
7. If the authors satisfy the reviewers’ comments, the paper is definitely accepted for publication.
8. As the editor of the “special issue”, I edit this issue.
9. The special issue is published in-line.

### Publication costs

As the open journals are free for readers, the publication fees are paid by authors or their institutions. The publication fees for “Metals” is 600 US\$ per paper. However, as the editor of this special issue, I got a special deal with the journal managing editor for one of the following options:

1. They accept to publish 5 papers free of charge.
2. They give 20% off for all papers.

I believe that the first option is better since we can offer it to the authors who cannot pay the publication cost.

**ICSoba Past Presidents, Managements and Board**

<b>NAME</b>	<b>PERIOD OF SERVICE</b>	<b>BOARD OF DIRECTORS</b>
1. Jean Papastamatiou (Greece)	1964 - 1969	Vice Presidents: Prof. Dr L. Maric (Yugoslavia), Dr György Bárdossy (Hungary) General Secretary: Prof. Dr R. Karsulin (Yugoslavia)
2. Dr György Dobos (Hungary)	1969 - 1973	Vice Presidents: M.L. Bobkov (USSR) Prof. Dr J. Nicolas ( France), Dr J. Roberts (USA) General Secretary: Prof. Dr R. Karsulin (Yugoslavia)
3. Prof. Dr Jean Nicolas (France)	1973 - 1978	Vice Presidents: Prof. Dr S.S. Augustitis (Greece), M.L. Bobkov (USSR), Dr György Dobos (Hung), Dr J. Robert (USA), Dr G. de Weisse (Switzerland), Dr. W. Wimberger (Austria) General Secretary: Prof. Dr O. Lahodny Sarc (Yugoslavia)
4. S.S. Augustitis (Greece)	1978 - 1983	Vice Presidents: Dr G. de Weisse (Switzerland), Prof. Dr J.L. White (USA), Dr György Bárdossy (Hungary), Dr. E. Mack (Austria), Prof. Dr Holtan (Norway) General Secretary: Prof. Dr O. Lahodny-Sarc (Yugoslavia)
5. Ivan Jurkovic (Yugoslavia)	1983 - 1988	Vice Presidents: Dr György Bárdossy (Hungary), Dr V.G. Hill (Jamaica), Dr Adolfo J. Melfi (Brazil), Dr A. Poignant (France) Prof. Dr D.G. Sapozhnikov (USSR), Prof. Dr J.L. White (USA) General Secretary: Prof. Dr O. Lahodni-Sarc (Yugoslavia)
6. Adolfo J. Melfi (Brazil)	1988 - 1993	Vice presidents: Dr G. Callaioli (Italy), A.M. Bartlett (Australia), Prof. H. Murray (USA), Prof. D. Nahon (France), Dr Wei Hunguang (China) General Secretary: Prof. Dr. O. Lahodny-Sarc (Croatia)
7. Dr György Komlóssy (Hungary)	1993-1998	Executive Director: Dr Karoly Solymar (Hungary) Vice Presidents: G. Callaioli (Italy), E. Cutshall, (USA), A. Franke (Germany), U. Kyriakopoulos (Greece), Prof. Dr P. Paschen (Austra) General Secretary: prof. Dr. O. Lahodny-Sarc (Croatia)



8. Prof. Dr Peter Paschen (Austria)	1998-2003	2002 - 2006 Executive Director: Dr Károly Solymár (Hungary) Vice President: Dr Lajos Tolnai (Hungary)
9. Dimitri Contaroudas (Greece)	2003 - 2008	Secretary General and Chairperson of the Council: Prof. Dr. O. Lahodny-Sarc (Croatia) Technical and scientific liaisons: Parris A. Lyew-Aye (Jamaica), Prof. I. Dragisevic (Croatia), Dr F.M. Kimmerle (Canada), Prof. Dr V. Siziakov (Russia), Dr H.W. Schimdt (Germany), Prof. Dr J. Thonstadt (Norway), G.M. Laks (Germany), G. Kirschner (Germany) Society Liaisons: Dr R. Huglen (Norway), Prof. Dr P. Paschen (Austria), Dr V. Risino (Italy) Regional Liaisons: Prof. Dr S. K. Bhargava (Australia), Dr V. Chjen (Russia), Dr A.K.Nandi (India), M.S. Thorabi (Iran), H. Zhao (China)
10. Roelof den Hond (Holland)	2008 – 2011	Vice Presidents: Dr Andrey Panov (Russia), Dr Li Wangxing (China) CEO: Dr Ashok Nandi (India) Secretary General: Dr Jeannette See (Canada) Director: Dr T.R. Ramachandran (India)
11. Dr Frank R. Feret (Canada)	2011 - 2014	Vice Presidents: Dr Andrey Panov (Russia), Dr Li Wangxing (China) CEO: Marja Brouwer (Holland) Secretary General : Dr Jeannette See (Canada)
12. Dr Ali Al Zarouni (United Arab Emirates)	2015	Vice Presidents: Dr Frank R. Feret (Canada), Dr Andrey Panov (Russia) Program Organizer: Michel Reverdy (France) Directors: Alexandre Gomes (Brazil), Dr Li Wangxing (China)

## Membership

ICSoba provides members with a platform to exchange technical information with each other. Upon their request individual members who are consultants or advisors to the aluminium industry, will be enlisted on the designated Consultants page on the website.

Companies can support ICSoba by becoming Corporate member. Corporate members are shown in every Newsletter and listed on ICSoba's web site. Corporate members can nominate two employees who have the same rights as individual members, such as reduced event delegate registration fee, Newsletters and voting rights. Digital proceedings can be made available to all employees at the company's intranet, and corporate members can sponsor ICSoba events at the reduced sponsor fee.

	<b>INDIVIDUAL MEMBERS</b>	<b>CORPORATE MEMBERS</b>
Reduced Sponsor rates at ICSoba Events		Yes
Reduced delegate registration fee for ICSoba Events	Yes	Yes for 2 nominated employees
Name listed in ICSoba's website	In Consultants page upon request	In Corporate Members page with link to web site
Right to vote on ICSoba matters and eligibility for Presidency and Council	Yes	Yes for 2 employees
Receive a digital copy of a full paper or full proceedings of a past ICSoba Event	Upon request	Upon request
Biannual Newsletter with articles from members, news and statistics	Yes	Yes to 2 employees. Company mentioned in Newsletters
Annual fee (from July to July)	CAD\$ 100	CAD\$ 500

You can find an application form for individual membership and corporate membership on ICSoba's website. You can also renew or apply for individual membership together with your registration for an ICSoba event.

## Website

Printed proceedings of past ICSoba events, the so-called Travaux volumes, have been scanned to separate searchable pdf files. There are a few exceptions, these are being searched and scanned as soon as possible. The Tables of Contents of the scanned Travaux volumes have been made public on the website <http://www.icsoba.org/proceedings>. ICSoba members can obtain digital versions up to 20 papers each year at no cost by sending an email request to Dipa [info@icsoba.org](mailto:info@icsoba.org). Additional papers are charged for C\$ 20 each.

Your feedback to make the website more attractive is welcome.

## ICSoba's executive office



Not only requests for past proceedings, but all inquiries sent to ICSoba, whether by email to [info@icsoba.org](mailto:info@icsoba.org) or by phone to + 91 982 328 98 17, are addressed by Ms. Sudipta (Dipa) Chaudhuri in Nagpur, India.

Also mailings and the underlying database of ICSoba's contacts are taken care of by Ms Dipa Chaudhuri in the executive office.