

The Alumina Technology Roadmap 4.0

Anne Duncan

Global Director, Bauxite and Alumina

HATCH, Louisiana, USA

Corresponding author: anne.duncan@hatch.com

Abstract

The Alumina Technology Roadmap (ATR) approaches its 20th year of contribution to our industry. The initial Roadmap was a strategic plan that contained the R&D agenda needed to address the industry's technical challenges over the next 20 years. Australia was the base for the Roadmap activities. With a common agenda, numerous collaborative partnerships were established between producers and research establishments. Productive research was carried out in areas such as solid liquor separation, air emissions, and residue. A challenge to any Roadmap is to ensure the strategy remains relevant and the goals are realistic. Since the first Roadmap, our industry has grown by 2.5 times with 90 % of the growth in China. Designing an engagement model for these new entrants will improve the global representation of the Roadmap. With these new players, we all are united with the recent and worsening climate change outlook. Not unrelated to climate change are the recent tailings failures which were not perceived 20 years ago to the same level of risk. With progress, we have entered the Industrial 4.0 Revolution which creates new efficiency opportunities. Behavioral safety continues to strengthen our safety culture. This paper summarizes the most recent 2018 ATR update and confirms we are working in the right areas. Engaging with all our global producers and creating compelling entrepreneurial business cases for the critical few initiatives are proposed next steps.

Keywords: Roadmap, Energy, Residue, Process, Digital.

1. Introduction

This paper summarizes the Alumina Technology Roadmap. From its origins as a US led Energy and Waste Reduction activity for Primary Aluminium, it has transitioned to a living guide for Alumina Industry Technology. At the time, Australia was the largest producer and exporter of alumina, and the Roadmap has been largely developed in Australia [1].

Today, the Alumina Technology Roadmap (ATR) is an initiative of the Alumina Technical Panel (ATP) sponsored by the International Aluminium Institute (IAI) through its advisory committee, the Bauxite and Alumina Committee (BAC). The Roadmap purpose and function were recently refreshed at the ATR 4.0 Workshop held in Gladstone in Sept 2018 [1]:

“The purpose of the Roadmap is to guide producers, suppliers and research providers in developing pre-competitive research programs aligned to the industries priorities. At its core the Roadmap holds the collective vision of the industry's future, an agreed set of the common goals and priorities, and a list of development infrastructure needs. An on-line forum for discussion is in progress. The function of the Roadmap is to provide inspiration and motivation for technology developers, and to leverage funding and collaborative efforts towards achievements and benefits beyond the resources of individual players. Through this process the Roadmap aims to improve the targeting and funding of research to maximise the rate of implementation of innovations, by helping bridge the “Innovation Chasm of Death” to allow research developments to come to fruition as beneficial new technologies”.

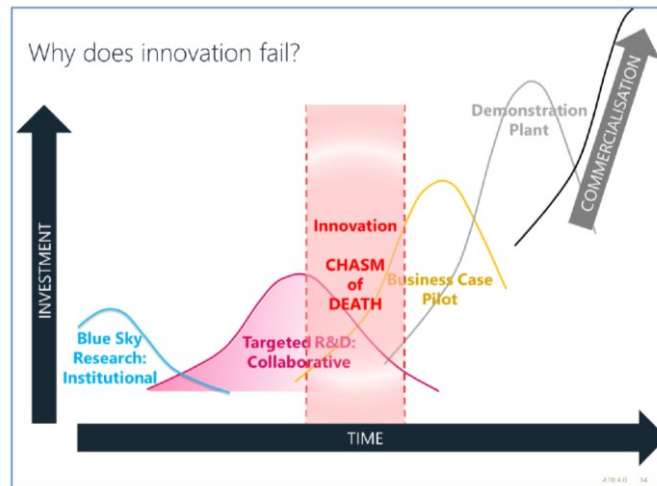


Figure 114. Innovation Timeline and the 'Innovation Chasm of Death' slide from [2].

As we approach the 20 year horizon set in in 2001, a timeline of Roadmap recaps the journey to date in Table .

Table 1: History of the Alumina Technology Roadmap.

Date	Intent	Activity
Oct-1996	Develop a vision for the future and a roadmap to achieve the vision. Specific focus was to 'Increase energy efficiency and reduce wastes in the production of aluminium'	US Dept Energy and Aluminium Association signed an 'Industry of the Future' agreement for industry led, Gov't supported pre-competitive research and development
May-2001	Enhance the long term competitiveness of the Alumina industry by establishing strategic goals for 2020	First Alumina Technology Roadmap developed by a steering committee for the framework for long term research and development plan deemed most significant in addressing the strategic goals [1]
2005	Broad industry membership with links to the board of the IAI	International Aluminium Institute (IAI) established a Bauxite and Alumina Committee (BAC) and sponsors Roadmap
2005	Clearer path forward for promoting and implementing the collaborative research and technology developments.	Alumina Technical Panel (ATP) comprising of R&D managers from 5+ of the major Alumina Producers reinvigorated. ATP serves to advise, project manage, and contribute technically to the BAC.
2006	Refresh the Vision	Minor Roadmap Update
April 2010	Extend the Roadmap to include the input of the Chinese Alumina community given the recent significant production increases and the unique bauxites in China	Updated Roadmap through with Collaboration with 21 of the 34 Chinese alumina refineries [1]
Sep-18	Envisage the Ideal Future and how to get there in targeted themes. These themes were Energy, Residue, Process & Technology, Industry 4.0 Digital, and Market Risks and Responses	ATR 4.0 Workshop with 100 delegates Workshopped the Roadmap within current 2018 context [2]

Specific Goals were stated for the 2001 and 2010 Roadmaps. Acceleration of Precipitation to increased yield by 20 % by 2020 and caustic reduction targets of 30 kg/t NaOH of 20 % were stated goals. Greenfield construction costs < \$500 / t and Brownfield < \$250 / t were Roadmap goals. Yield and soda benefits did occur, but only to the extent of the a few %. Capital costs worsened.

The 2006 and 2010 roadmap updates included ranking of priorities. While the activities were not simultaneous, this activity does give some insight into the differences on priorities with Chinese Producers and predominantly Western Producers represented on the ATP (Table 2). Bauxite Quality is the dominant theme of interest to Chinese producers. Western producers ranked Impurity Removal as the highest priority. While priorities are related, the clear overlap was Residue. Residue was ranked slightly higher by Chinese (3rd) in comparison to Western (5th) alumina Producers. Differences were also evident with Energy and Sintering identified as top 5 Chinese issues. In comparison, Western producers included emissions (mist, VOC's, dust, CO2), scale, and the slow rate of precipitation in their top 5.

Between 2009 and 2019, China tripled the production of alumina. This increase accounted for 86 % of the 59 Mtpa increase in global annual production (HATCH database). This significant extraordinary Chinese growth and rebalancing challenges the currency and alignment of the Roadmap. Commonality of rankings may improve with Guinean bauxite dependency in China.

Table 2. Comparison of the Roadmap Rankings by Chinese and Other Producers.

Rank	2010 Chinese Producers [4]	2006 Priority R&D Roadmap Areas [2]
1	Bauxite Quality (processing low grades)	Impurity Removal
2	Energy Savings	Technical Solutions for Refinery Releases (Emissions)
3	Residue Management	Scale Management
4	Innovative Sintering Process & Series Process	Alternative Methods for Accelerated Precipitation
5	Product Quality Improvement	Residue Management

Suppliers also had input into the 2010 update. We should acknowledge improvements in our industry from suppliers. Products such as Max-HT have partially decoupled silica scaling and silica concentration in dual stream digestion. Diphoterine (DAP) has significantly reduced the severity of caustic burns for our team members who treat skin and tissue following exposure.

2. ATR 4.0

The 2018 ‘ATR 4.0’ for the 4th industrial solution was designed with a more forward looking approach developed with 4 key themes:

1. **Energy of the future** – How to decarbonize our industry with an opportunity for a step change to our carbon footprint
2. **Residue** – Is it realistic for Zero Hazardous residue from the Bayer Process
3. **Process Science and Technology** – What are the core process science and technology advancements required to solve our problems and achieve our aspirations for the industry
4. **Industry 4.0 – the Digital Revolution** where using the power and ubiquity of the digital and data revolution to enhance safety, productivity, and business performance in our industry.

A summary of the vision, goals, and enablers for each theme is in Table. Outcomes from the workshop are described in 2.1 to 2.4.

Table 3. Summary of the Vision, Goals, and Enablers from 2018 ATR 4.0.

	Vision	2050 goals	Enablers
Energy of the Future	Reduce Usage with Closing the gap to the practical limit of 3.3 GJ/t (including calcination) Reduce Carbon Intensity with Renewables, CO ₂ Capture, hydrogen Technology	2 GJ/t Reduction Globally Defined pathways to 2 GJ/t Exceed Expectations - SO ₂ , NOx, PM, dust, odour	Pressure Calcination, Calcination heat Recovery, boehmite precipitation Waste Energy Capture Improved Transmission Energy Storage in Residue Alumina Chlorination
Residue or not	Reduce footprint with 100% utilization of residue with positive Economic and social outcomes Zero Harm with non hazardous GHG reduction positive products synergistic to others	Zero long term residue storage Active Reprocessing or remediation of historical impoundments	Social and Regulatory Buy in to a new <i>product</i> not a <i>waste</i> Producer Buy-In to solve the problem Viable Markets established
Process Science and Technology	No fresh water or caustic added to process Minimize Liquor impurities One Step Solid / Liquor Separation Zero Scale	100 % Recycle of caustic and Water Effective Impurity Removal Thickeners and Counter current washers replaces with high temperature filtration Successful Scale mitigation	Soda Recovery from DSP Steam elimination and capture, water conservation Single stage Red-side Filtration Reduce / Recycle DSP Effective anti-scaling agents
Industry 4.0 - The Digital Revolution	Day to Day Operations is by Machine People Manage License to operate, set goals and strategy, monitor outputs and provide control and feedback as required	Industry 4.0 principles well understood and embedded in industry culture Substantial implementation of intelligent refinery Extensive low cost highly capable and intelligent sensors Uniform specifications and standards within a highly secure digital environment	Business Case and Framework for Industry 4.0 Limited suitably skilled and knowledgeable people, Cheap reliable instruments, Data standards and portability

2.1. Energy of the Future

The ATR 4.0 Panel discussion acknowledged Climate Change is the defining issue of our time. We are at a pivotal moment with an Urgent Roadmap at the United Nations level addressing GHG reduction well underway. Accounting for about two-thirds of GHGs, is the carbon dioxide (CO₂)

from burning fossil fuels [1] of which our industry is a contributor. Aluminium allows significant energy savings in many applications including lighter vehicles, energy efficient buildings, etc. whose recycling requires 95 % less energy than primary production [1]. Mainly as thermal energy for digestion, the alumina refining energy is ~ 20 % of the total for the entire production of Primary Aluminium. Within the industry, the ranking of #1 for Bauxite Quality and #2 Energy by the Chinese Producers reflects the high energy required for low grade high silica feedstocks that are processes in high temperature Bayer and Sinter plants. Similar to Smelting where the theoretical minimum energy needed for the electrolysis of less than half what has been achieved in best practice [1] a similar ratio is observed in Alumina. An ATR 4.0 target for a conventional flowsheet was proposed as 3.3 GJ/t or roughly half of best practice. Regarding usage, the participants noted the requirement to achieve the other business targets including aluminum product quality and the importance to consider energy in the total aluminum supply chain from mine through the process. All systems are unique. Estimates per tonne of bauxite mined indicate the heavy vehicle fuel requirement is about 1/3 the daily fuel requirement while shipping. 2018 estimates are 178 MT of the 337 MT of bauxite processed was not used domestically, but exported to another country. While small in comparison to the total energy, shipping energy is an example of consideration of the total supply chain.

In addition to usage, fuel type and refinery configuration influence the carbon footprint and operating cost. A number of energy source goals were suggested at ATR 4.0 including coal gas, and bio fuels. LNG availability enables refinery fuel switches. However insufficient focus on energy projects can occur because refinery energy costs are so low with available economical coal. Government Policy influences capital decisions. However, hesitancy to invest occurs when policy changes are observed in shorter timescales than Projects can be brought to fruition.

Hydroelectricity typically attracts a smelting industry, but more recently abundant gas in the Middle East has encouraged large scale primary aluminum development with adjacent high capacity refineries. This model is aligned with the ‘Alumina Refinery of the Future’ description of the ‘Energy Centre Scenario’ [7]. In this scenario, there is a business case to bring the refinery to the energy source. The opportunity for cogeneration typically reduces primary fuel by 15 % with heat and power produced simultaneously. Additional cost benefit can be substantial and depends on local power market. Energy recovery opportunities including calcination steam, calcination coolers, blow off were considered and the multiple low grade energy sources highlight the challenge. Limiting the disruption in the demise of Western coal and seizing the opportunities in the rise of renewables is a shared issue.

It was highlighted that alumina producers typically focus on incremental process efficiency improvements. R&D innovative projects are not the usual. While there is a lot of government funding (ESCO in Europe, Australian Solar, etc.) the Entrepreneurial requirements to seek an industrial partner and Co-develop a Step Change in Energy Technology is not the typical skill set practiced in the operations.

2.2. Residue or Not

The residue vision is more complex than the other themes. Tailings dam failures in our industry (Ajka, 2010) and similar industries (Samarco, 2015) have occurred. However, the Brumadinho (2019) failure event occurred after the ATR 4.0 Workshop. This recent event reminds our industry of the maximum reasonable consequence that can occur – especially with increase frequency of severe weather events at our tailing impoundments. Risk reduction are benefits from transforming our residues into non hazardous beneficial products. Roadmap goals focused on rebranding to recognize residue as a *product* eliminate the negative *waste* connotation. An opportunity to ‘share the problem’ with a broader community including government and legislators to engage others with potential funding, solutions, and uses was proposed. One

suggestion was to foster alumina research in public research institutions, than current alumina specific facilities. A possible funding idea was an optional Red Mud Levy. Within this construct, producers could agree to contribute to a funded entity which would develop technology for royalty free usage of the solution. Other development stimulus activities included supplementing the Residue Technical talent with specialists fund-raising from sources in R&D and Government. There was a realization that intentional collaboration outside the industry would be beneficial for this issue.

The expectation is residue solutions are unique to a refinery and will have the highest probability of success when developed under modern mud filtration with in control water balance, and a ‘pull’ for products such as topsoil. Service Level Agreement for on specification feedstock for mud treatment may introduce new challenges in the refinery connected to the residue treatment.

2.3. Process Science and Technology

Aspirational technical goals for generation and recycle of water and caustic require new ways of problem solving. With focus on Redside, features of potential novel flowsheets included single stage red side filtration to replace the system of conventional settlers, washers and security filtration. High efficiency mud filters and DSP separation and regeneration were identified as steps required for the goals. Emerging technologies included sensors and anti-scaling agents. Molten Salt substitution for Steam was suggested as an opportunity to improve heat transfer.

The Process Science and Technology enablers were dominated by social enablers. Improving training, attracting external team members and fostering a stronger collaborative culture were proposed as opportunities. Specific changes required include elevating problem solving to look at the bigger picture and interacting with other industries. This broader and external approach is in contrast to the day to day focus on technical optimization the status quo. Barriers to implementation included over protection of Producer IP, and a risk adverse mindset.

2.4. Industry 4.0

As a new entrant to the Roadmap, Industry 4.0 refers to the fourth industrial revolution. It will take mass production with the adoption of computers and automation (3.0) and enhance it with smart and autonomous systems fueled by data and machine learning (4.0). In its scope is the ‘Internet of Things’ which refers to the interconnection via the internet of computing devices embedded in cheap and reliable instruments and sensors in refinery circuits enabling them to send and receive data. It was proposed that in-scope included digitalisation, business flows, Biotec & robotics (drones) and training. Gaps identified were quantified business cases for using Industry 4.0, upskilling, instruments, and data standards. Establishing a committee to agree on the standards for open source data was proposed as a key upfront activity to lay a robust and secure foundation. These standards may be largely replicated from other industries who have already embarked on the journey. Online courses and strong management support were suggested as options for upskilling. A digital twin refinery would ‘learn’ the refinery responses for day to day operation allowing plant optimization.

Previously, the Roadmap was used to stimulate Research and Development Activities. In the case of Industry 4.0, resources required are likely to be technology practitioners working alongside site personnel rolling out quick wins after short controlled pilots.

3. The Changing Landscape in which the Roadmap is Delivered

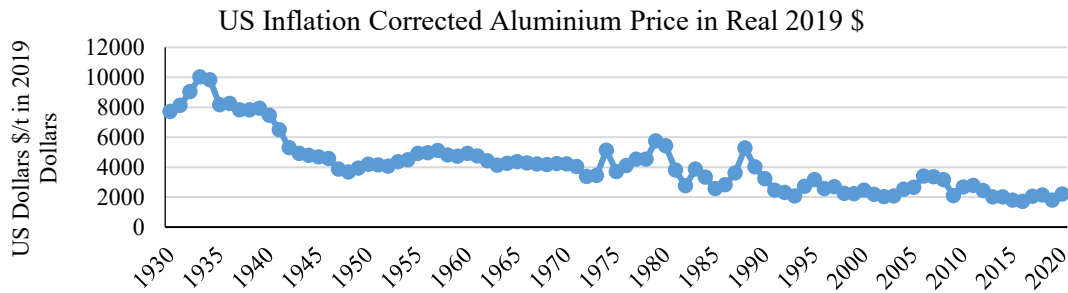


Figure 2. US Inflation Corrected Aluminium Price in 2018.

3.1. Price Reduction

Smelter Grade Alumina remains the production pathway to Aluminium, and the Metal Price [1] is the key influencer of the Alumina Market. The continuous downward trend confirms it has been produced with rapid technical changes in its manufacture and its raw materials are not in scarcity. Year on Year volatility in metals price continues. Since the Roadmap inception, inflation corrected prices have between cycled 31 % below to 42 % above the average annual price. Aluminium industry growth is significantly stronger than other metals and also ahead of steel. Regarding the Roadmap, competing business pressures at the top and bottom of the price cycle and economic events can and have distracted support.

3.2. Distribution

The strong collaboration with the ATP & BAC & IAI have supported the collection of useful pre-competitive statistics. The Material Flow Balance for Aluminum Production in 2018 is one such statistic in Figure 3. This balance represents estimates of the Alumina and bauxite flow to achieve the 2018 market scenario. What this balance doesn't indicate is the variability and interchangeability in the materials in each step. While variations in Pre-bake vs Soderberg technology, cell amperage, and emissions treatment exist, industry commonality is clear with carbon anodes, cryolite, and repetitive pots. Of significance is the tight alumina quality specification for SGA to the smelters which is means alumina feed can be interchangeable. Alumina source is determined by business case – and factors such as co-location to a refinery, integrated producer, and freight often prevail over smelter technology match to feedstock (with the exception of sandy vs floury).

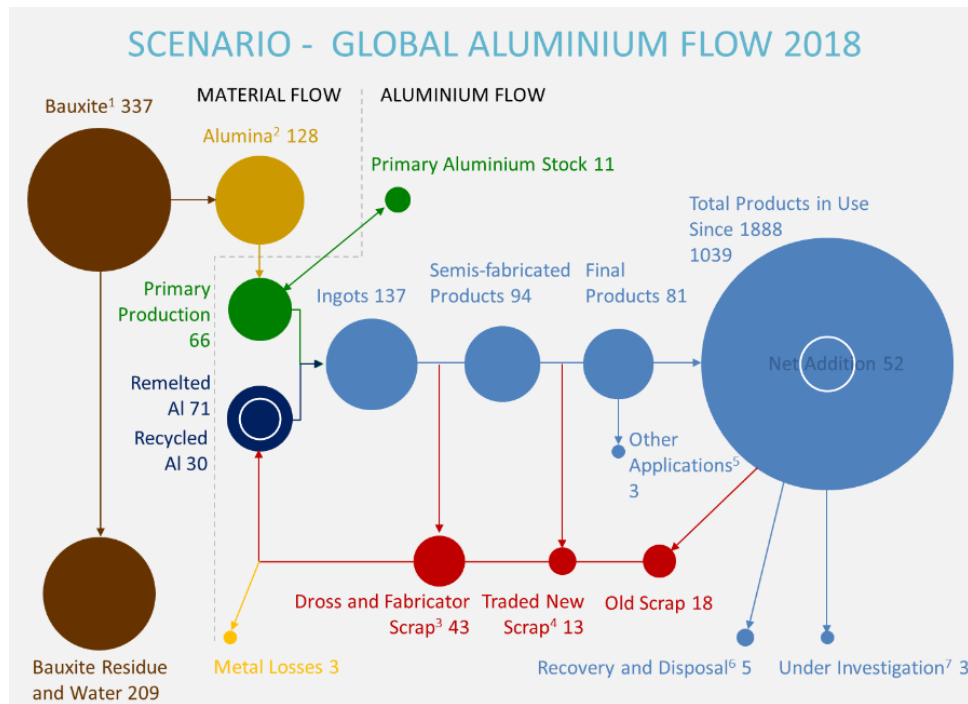


Figure 3. Global Aluminum Flow in 2018 [9].

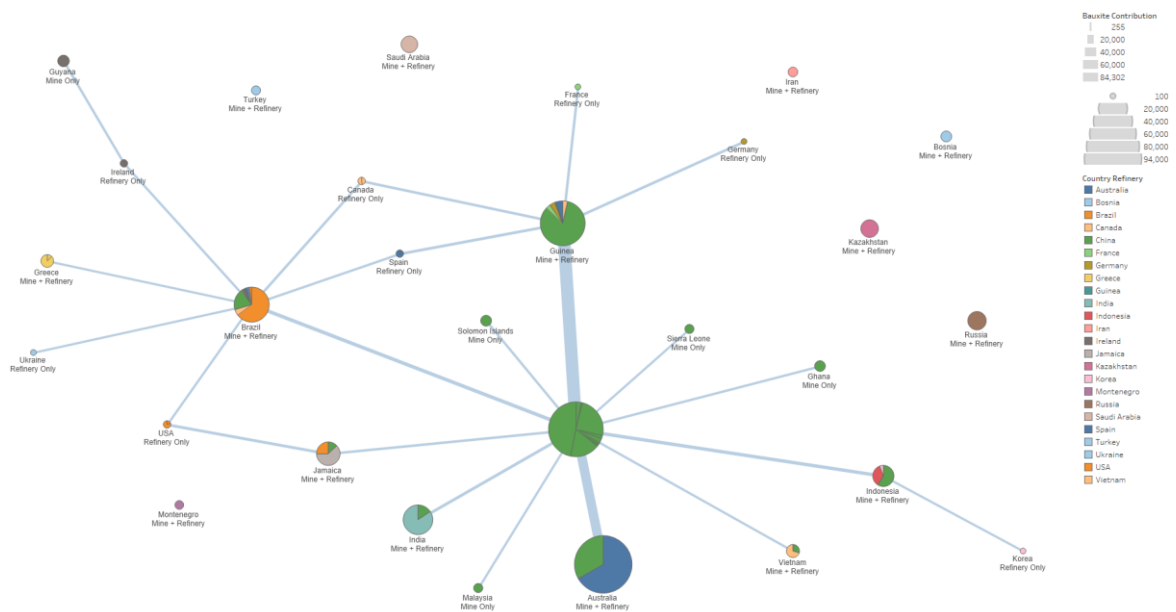


Figure 4. Bauxite Source and Destination (HATCH estimates from public domain).

In Refining, the interchangeability in feedstock is limited to caustic. Refinery technology is specific for a bauxite type. The Material flow in Figure 3 does not reflect the multiple sources. The connectivity map in Figure indicates the complicated bauxite supply routes. This data was estimated for the 2018 balance of production to best known estimates. Some sites such as Ma'aden are single refinery / mine. Other sites such as in Canada source bauxites from two continents. Implications for the Roadmap are that the complexity industry supply chains. Useful R&D for one site may have limited transference to other sites.

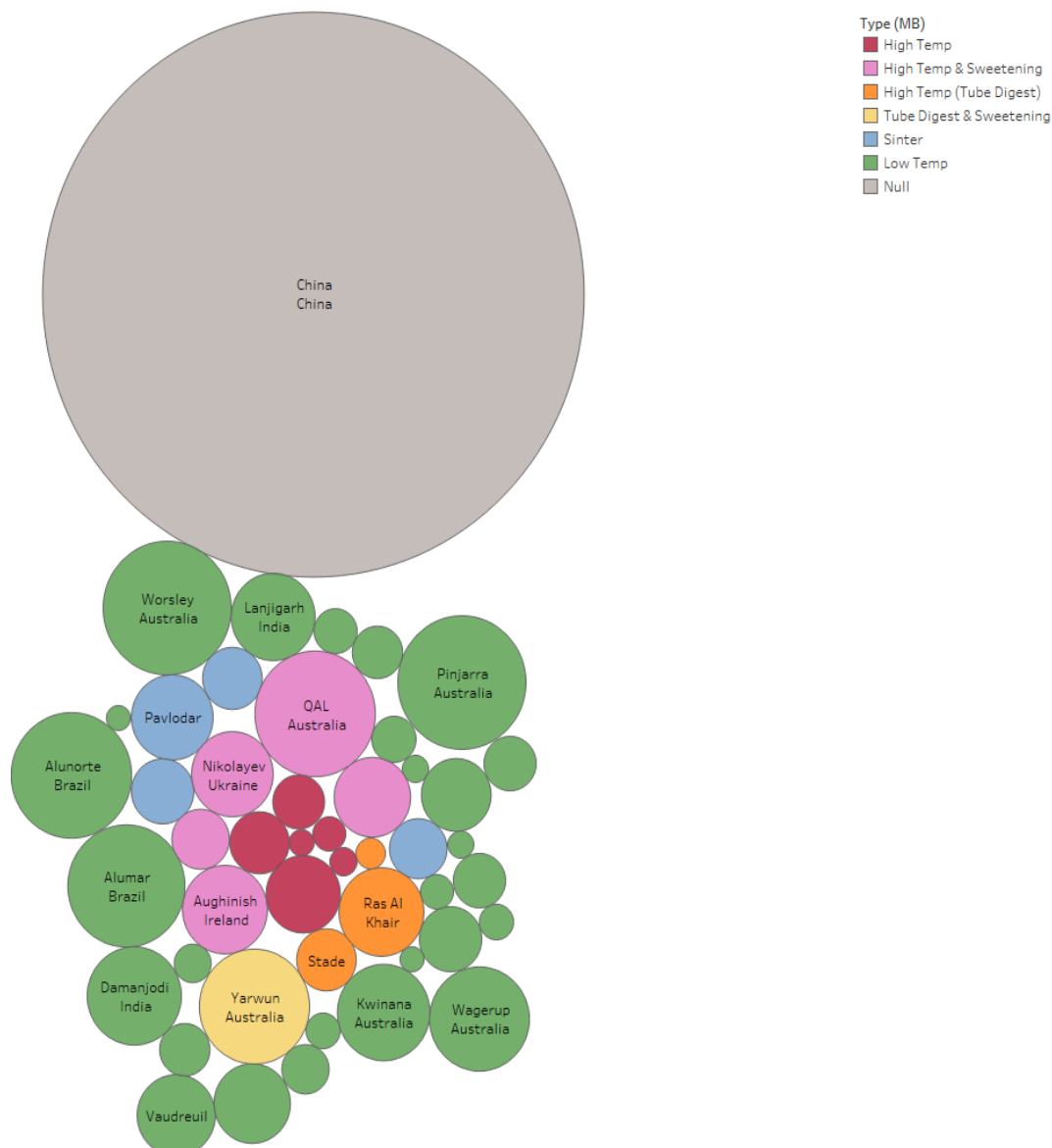


Figure 5. Refinery Capacity and Configuration with Bubble Size Proportional to stated Capacity (HARBOR) and colour indicative of Digestion Technology.

The refinery capacities (nameplate) and configurations in Figure indicate the variability in sites under the Roadmap. This is due to a range of issues including site customization for bauxite type, owner integration, etc. The lower standardization adds complexity to unlock value and sustainability when applying pre-competitive generic solutions across dissimilar entities. In addition, the Chinese producers are represented in Figure by a single capacity of ~ 85 Mtpa due to the relative unfamiliarity of specific technologies and configurations in China. The Chinese R&D providers have largely and successfully supported the Chinese industry.

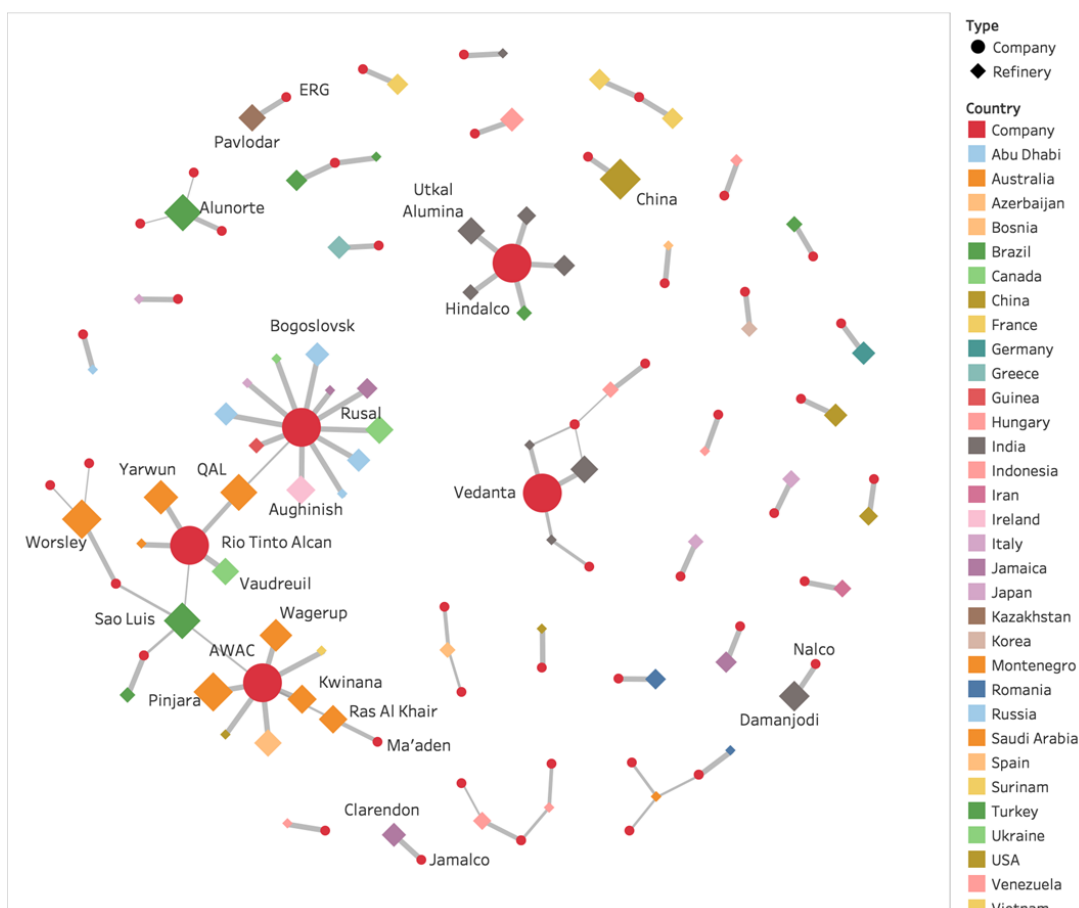


Figure 6. Network Diagram for the Refinery Sites.

Hurdles for Pre-competitive collaboration are lowered when the priorities are common, outcomes are high impact, and the resources for the solution are not within sites. While not fully accurate (HATCH public domain inputs), the Network diagram for Producers and Refineries (Figure) indicates the complexity and distribution of the global competitors.

4. Implications for the Roadmap:

The ATP is developing the launch of the ATR Website (Figure). Preferences are for a multi-language site with strategic, training, benchmark and performance. Links and useful information for EU Research initiatives and public and government sector support programs. Most importantly, it will facilitate interaction for alumina practitioners to exchange ideas and information to improve and sustain their businesses.

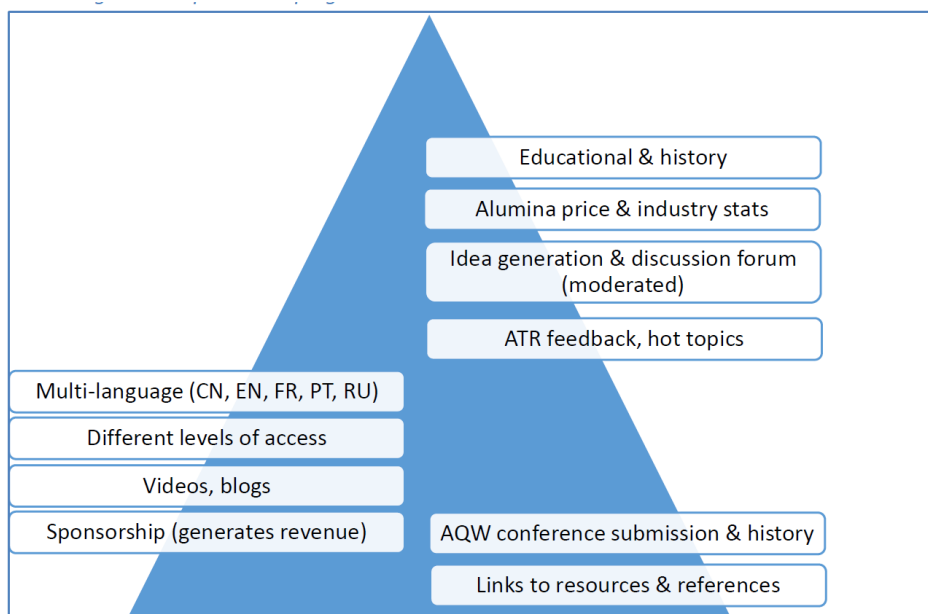


Figure 7. ATR 4.0 Living Roadmap Website.

5. Roadmap Implementation:

- Since 2001, the Roadmap has retained its intent to provide a strategic plan based on the collaborative input of Alumina Producers. While the strategic targets were not fulfilled, many new learnings in priority areas contributed to small step improvements and regulatory benefits.
- Opportunities include embedding an ATR Website to maintain momentum outside of Roadmap workshops. A website also permits the engagement of all global producers. Geographic and language barriers are lowered with this virtual community.
- Maintaining currency of the Roadmap during global issues such as climate change, tailings scrutiny, Industry 4.0 Revolution, and increased alumina demand are key to its relevance.
- The ATR 4.0 update focused its sights on Residue, Energy, Process, and Industry 4.0.
- Carbon footprint, Water, and Residue remain the common high cost, high impact, and high risk areas for collaborative action in our industry. Changing our model to seek input outside the industry, create business cases, and adopt entrepreneurial entities to accelerate the delivery of step change technology are reasonable short term approaches.

6. Acknowledgements

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