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USE OF THE LIFE CYCLE ASSESSMENT METHODOLOGY TO SUPPORT SUSTAINABLE ALUMINUM PRODUCTION AND TECHNOLOGY DEVELOPMENTS

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Abstract

Life Cycle Assessment (LCA) methodology is emerging as a standardized reference for assessing the comprehensive environmental impact from any product or process. This holistic approach considers all steps related to the product/process life, from cradle to grave. As an aluminum producer, Rio Tinto Alcan (RTA) recently applied this method to assess its relative performance compared to the industry average, with a specific focus on its GHG (Greenhouse Gas) emission intensity. As a smelting technology supplier, RTA is now deploying a simplified approach based on LCA principles to assess technology performance. Combined with specific accounting techniques, this should allow for more efficient designs, both from an environmental and financial perspective. This paper illustrates, through some examples on product and process assessments, how this philosophy can be used to design and operate sustainable technology solutions in a systematic way.

Introduction

Increasing awareness of the importance of sustainability and of the potential environmental consequences associated with products and services has sparked the development of innovative methods to better understand, measure and reduce this impact. The leading tool for achieving this is Life Cycle Assessment (LCA), an internationally recognized methodology defined by the International Organization for Standardization (ISO) 14040-14044 standards [1, 2]. Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact that their use or release has on the environment. Life Cycle Impact Assessment (LCIA) provides the basis for analyzing the potential contributions of resource extractions and emissions in a Life Cycle Inventory (LCI) to a number of potential impacts.

The method used here to assess environmental impact is the peer-reviewed and internationally recognized LCIA method IMPACT 2002+ [3]. This method assesses 17 different potential impact categories (midpoint) and then aggregates them into four endpoint (damage) categories, which are as follows:

- Climate change - in carbon dioxide equivalents (kg CO_2-eq)
- Human health - in disability adjusted life-years (DALYs)
- Ecosystem quality - in Potentially Disappeared Fractions over one year for one square meter of land (PDF*m^2*y)
- Resource depletion - in megajoules (MJ)

The "screening LCA" approach, used in some of the cases described in this paper, is based on the above LCA methodology, but presents three main differences:

- More generic data are used: for instance where specific information is not available, the industry average value is chosen,
- Analysis can be less detailed, with fewer indicators and/or with fewer sensitivity analyses,
- Results are not peer-reviewed.

The "screening LCA" approach therefore provides a fair idea of the main conclusions of a full LCA, both faster and with fewer resources.

As a primary aluminum producer, RTA has recently been involved in such LCAs, both for its own internal benefit and as part of global industry initiatives. On the strength of this experience, it has decided to assess the benefit from such an approach in a technology design context, where demonstrating superior environmental performance to stakeholders – clients but also regulatory authorities, local communities, etc. – is increasingly becoming a pre-requisite. A few selected examples will be presented in this paper, as well as the main lessons derived from them.

Application to the assessment of the environmental impact associated with primary aluminum production

Quebec ingot carbon footprint

In 2013, the International Aluminium Institute (IAI) published the "Global Life Cycle Inventory Data for the Primary Aluminium Industry" report (IAI 2010 LCI) [4], an update for data year 2010 following similar reports for 2000 and 2005. Its purpose is to "characterize accurately and at global level, resource inputs and significant environmental releases associated with the production of primary aluminium". As such, this report is the reference material for environmental assessments for life cycle practitioners when regional or site specific data are not available. The corresponding data have now been integrated into major LCA databases (EcoInvent, Gabi). In 2014, the IAI published the Environmental Metrics Report [5] which complements the previous report by delivering Life Cycle Impact Assessment (LCIA). The results presented in this paper are based on LCIA work conducted prior to the publication of the IAI LCIA report. Differences between the results presented in this paper and in the IAI LCIA report can be explained by the use of different LCIA modelling assumptions, methodologies and databases.

In parallel to the IAI 2010 LCI report, a study conducted by Quantis on behalf of the Canadian Aluminium Association, in which RTA actively participated, assessed the average carbon footprint generated during the cradle to grave life cycle of an aluminum ingot produced in the province of Quebec. This exercise was part of a 1-year pilot project on the carbon footprint of products led by the Quebec Government. It was conducted in conformity with the GHG Protocol – Product Life Cycle Standard (2011) [6].

Given the fact that the aluminum ingot is an intermediate product, use, end of life and recycling stages were not considered. When Quebec specific data were not available, IAI 2010 LCI data were used. For areas outside the boundary covered by the IAI 2010 LCI report, data from EcoInvent were used, as shown in Figure 1.

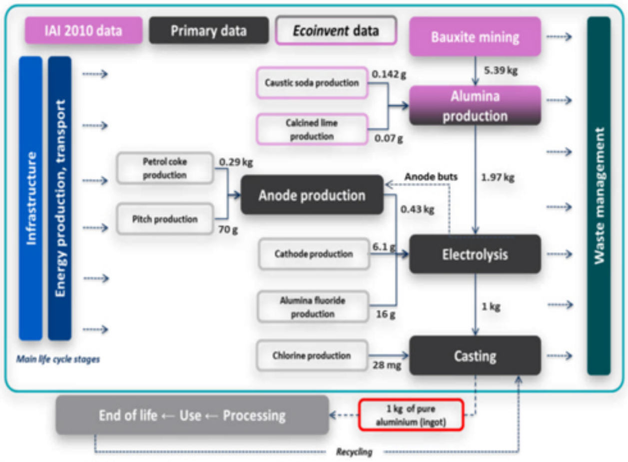

Figure 1. Life cycle stages of aluminum production

The study concluded that production of one metric ton of aluminum ingots in Quebec in 2010 generated on average 4.78t CO_2-eq, which is much lower than the industry average mostly due to the fact that this aluminum is produced using hydroelectricity (refer to Figure 2). The steps that contributed most were Electrolysis and alumina production (49% and 38%, respectively).

The fact that emissions from Electrolysis (also referred to as direct emissions or Scope 1 emissions) came out as the biggest source of CO_2 emission was no surprise. These emissions, which occur on the production site, have been tracked by industry for a long time now. Also, indirect emissions or Scope 2 emissions, which refer to the emissions generated during electricity production, typically represent an important part of an aluminum ingot footprint. In the case of the Quebec ingot, which is produced using hydroelectricity, Scope 2 emissions are very low.

On the other hand, Scope 3 emissions, which refer to all emissions that can be associated with the product, outside of Scopes 1 and 2, are not traditionally tracked by the industry. Consequently, it was not expected that the impact from alumina production would be so significant in relative terms – especially considering the fact that the RTA Vaudreuil refinery in Saguenay, which produces part of the alumina consumed in Quebec, has one of the lowest GHG intensities in the world.

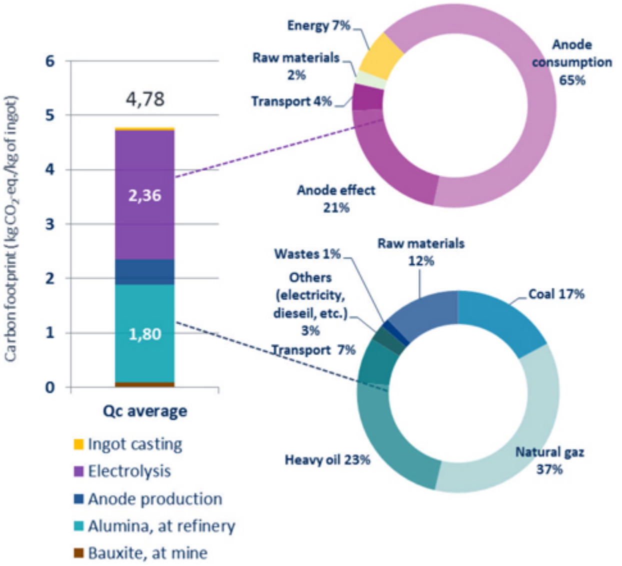

Figure 2. Carbon footprint of 1 kg of pure aluminum production - Quebec average

The main conclusion drawn from this study was that the current level of development and harmonization of methodologies is not sufficiently advanced to support a labeling aimed at comparability or a consumer-oriented certification in Quebec. On the other hand, it was also highlighted that companies can benefit from measuring and communicating their carbon footprint. It was also noted that Product Carbon Footprint (PCF) and LCAs represent strong market trends to which companies must respond to ensure long term success.

Rio Tinto Alcan ingot carbon footprint

Following the interesting conclusions of the Quebec project, RTA mandated Quantis to evaluate the carbon footprint of an aluminum ingot produced by its smelters in North America (NA) and Europe, still in accordance with the methodology under the GHG Protocol – Product Life Cycle Standard (2011) [5]. Only managed smelters currently operating in 2014 were included in the study.

Using as far as possible an identical methodology and perimeter as in the Quebec study, it was determined that the 2010 footprint of the aluminum ingot produced by RTA in NA and Europe was 4.99tCO_2-eq, which is approximately a third of the global average (refer to Figure 3). This enhanced performance is essentially related to a difference in the electricity mixes used for aluminum production. RTA indeed benefits from a very favorable GHG intensity for its electricity supply. Since 2010, efforts of portfolio optimization and modernization have been undertaken which has further reduced RTA's carbon footprint.

Several sensitivity analyses were performed on the high contributors and more uncertain parameters, i.e. bauxite and alumina origin and modeling of process emissions during the Electrolysis step. These showed that the total carbon footprint is not significantly affected by these uncertainties.

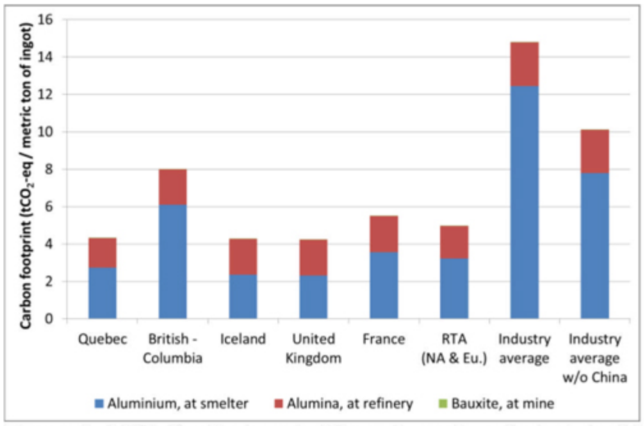

Figure 3. 2010 Cradle to gate life cycle carbon footprint of 1 metric ton of aluminum

This study also highlighted the fact that almost 40% of RTA's emissions for aluminum production in NA and Europe are not related to Electrolysis. This can be accounted for by the successful efforts conducted by RTA, along with the rest of the industry, over the last 30 years to reduce perfluorocarbon (PFC) emissions.

Downstream applications

The next step in the product-oriented LCA appropriation process for RTA is to continue to provide LCI data to its customers and to develop LCA expertise for aluminum products. As an example, the automotive industry can highly benefit from vehicle light weighting.

Vehicle light weighting is an important method for improving fuel efficiency and thus reducing GHG emissions. A screening LCA was performed to evaluate potential benefits over the lifetime of a car. Figure 4 shows the GHG emission savings resulting from the replacement of steel parts, namely a front hood or a body-in-white, by aluminum parts sourced from RTA. It is clear that using aluminum to reduce the weight of passenger vehicles helps reduce GHG emissions and energy consumption.

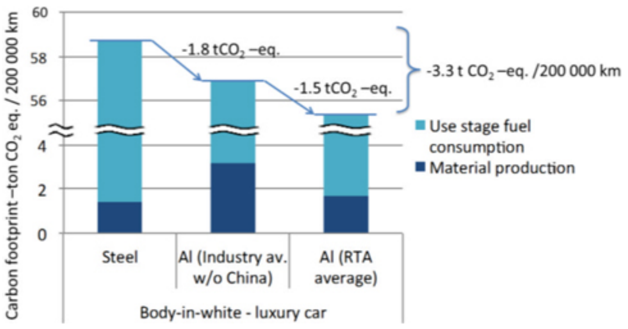

Figure 4. Carbon footprint comparison of cars with lightweight aluminum parts sourced from RTA

Next steps

RTA will continue supporting improvement of the LCA methodology. As an example, as part of a work group within the IAI, it is working with the scientific community towards refinement of indicators for Ecotoxicity, which will allow for better quantification of metal toxicity impact on human health and the environment. Work on development of a water scarcity footprint indicator, which will allow the impact on local water scarcity of different production sites or processes to be compared, is also ongoing.

RTA is also collaborating with some of its customers by providing LCI data and LCA expertise. Integrating data into their LCAs allows them to assess the benefits of using RTA aluminum in their specific applications. By so doing, RTA seeks to promote the use of LCAs in the main aluminum markets as a way to identify the sources of aluminum supply with a lower environmental impact, such as RTA's aluminum.

Application as a tool for technology performance assessment and design

First RTA experience of LCA-based technology assessment

The now well-established LCA methodology has thus recently been applied by RTA in a few cases in a production context, and the question was raised whether it could also be beneficial as a tool to assess the relative environmental footprint of different technological options. The methodology was thus applied to evaluate a few sulfur dioxide (SO_2) treatment solutions. This example had been expected to be particularly illustrative of LCA's benefits in a technological context, as well as of its current limitations.

Today, several technological options are available to treat SO_2 from pot gases, most of which are wet-based, including sea water, soda and sodium carbonate scrubbers. RTA commissioned a LCA-based study, aimed at assessing their relative footprint, still based on the same methodology (IMPACT 2002+). As such, it was one of RTA's first experiences of applying LCA in a technological context.

	Seawater	**Soda**	**Sodium carbonate**
Emissions	25kgSO_2/tAl	25kgSO_2/tAl	25kgSO_2/tAl
Main inputs	567m^3 of seawater	56.6 kg of NaOH (50%)	37.5kg of Na_2CO_3
Efficiency	98%	93%	93%
Electricity	131.6kWh	110.2kWh	110.2kWh

Table 1. Main reference data associated with each technology

The studied function was the treatment of atmospheric SO_2 emissions from the Electrolysis sector by wet scrubbing. In all three cases, the liquid effluents are assumed to be treated through an aeration system (to transform sulfites into sulfates and for pH control), prior to a direct release into the sea. The scrubber is assumed to be operated from a "grid mix" consistent with the IAI 2005 LCI, since 2010 data were not finalized at the time of the study. Inputs/outputs (raw material and electricity consumptions) are derived from a feasibility study conducted in one RTA AP3X smelter, and the main reference data are summarized in Table 1. In this study, the impacts on all 4 damage categories were computed, and the results are shown in Figure 5.

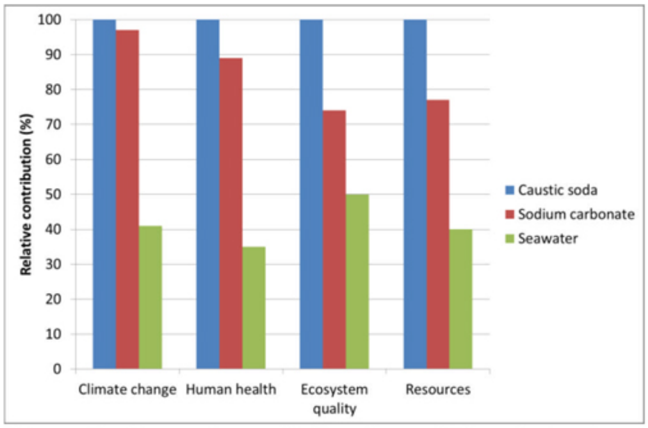

Figure 5. Comparison of the three different treatment technologies

One of the main limitations of the study is that the methodology did not allow us to take into account the detrimental impact of the liquid effluents to the sea, nor of water intake. In this respect, it is thus not possible to conclude as to whether wet scrubbing SO_2 is globally better for the environment than no treatment at all (i.e. that it is not a mere pollution transfer from atmosphere to sea water). On the other hand, assuming that the seawater impact from all three wet scrubber technologies is identical (same quantity of sulfates released in all cases), it is still possible to assess their relative performance.

This example was therefore useful to illustrate how the LCA approach takes into account "external" impacts and provides a different evaluation from that which a traditional environmental assessment would have provided. In the strength of this experience, it was decided to evaluate whether this methodology could also be applied as a tool to orientate smelting developments towards a lower environmental footprint.

Evaluation of LCA potential in a smelting technology development context – Scope and goals

As discussed above, one of the main benefits of LCA is that it allows quantitative balancing of the environmental pros and cons associated with different alternatives. Indeed, traditional environmental assessments, based on a few indicators that are not inter-related (fluorides and PFC emissions, water usage and discharge, energy consumption, disposed spent pot linings, etc.) make it difficult to evaluate the global – "intrinsic" – environmental performance from a smelting technology. For a new cell generation, some indicators might be enhanced at the expense of others, sometimes unintentionally. In theory, a LCA-based approach should help resolve these contradictions as it takes into account all impacts from upstream processes and aggregates them at a level that makes overall assessment possible.

The intention was therefore to test the approach by conducting a screening LCA on the most recent AP technologies (APXe and AP60) compared to a reference (AP35) case. The goal was not so much to acquire an absolute evaluation of the environmental impact but to obtain a relative performance assessment of the different technologies. It was thought that this new perspective could open up new development opportunities aiming at continuously improving technology sustainability.

System boundaries and hypothesis

The reference case is based on an existing 347 ktAl/year smelter equipped with AP35 pot technology (360 pots), a carbon plant (paste plant and baking furnace) and a casthouse producing pure aluminum ingots (no alloy). The plant is located in the Middle-East and, in keeping with this hypothesis, electricity is provided by a gas-fired power plant. It is assumed that the bauxite mining and alumina refining impacts correspond to the average IAI 2010 LCI assessment. Process water is supplied by a dedicated desalination plant, which is mainly considered through energy consumption. System boundaries are identical to those described above, meaning that they include all upstream impacts (bauxite mining, alumina and electricity production, etc.). All results are reported for production of one metric ton of aluminum ingots at the smelter gate. Data were collected (list of considered material input, emissions, etc.) in accordance with the list used by the IAI 2010 LCI, recalled in Table 2.

Material input	**Air emissions**	**By-Products (a)**
Bauxite	Particulates	Bauxite residue
Caustic soda	*of which <2.5µm*	SPL carbon (c)
Calcined lime	Carbon monoxide	SPL refractory
Fresh water	Carbon dioxide	Refractory
Sea water	Sulfur dioxide	Steel
Petrol coke	Nitrous oxides	Dross
Pitch	Mercury	Filter dust
Refractory	Particulate fluoride	Scrap sold
Steel	Gaseous fluoride	Other
Alumina (dry)	PAHs (EPA 16)	**Solid waste (b)**
Cathode carbon	Benzo(a)pyrene	Mine solid waste
Alum. fluoride	Benzene (d)	Bauxite residues
Electrolysis metal	Tetrafluoromethane	SPL
Alloy additives	Hexafluoroethane	Waste alumina
Chlorine	Hydrogen chloride	Waste carbon/mix
Energy input	Dioxin/furans	Scrubber sludges
Heavy oil	**Water emissions**	Refractory
Diesel oil	Fresh water	Dross
Natural gas	Sea water	Filter dust
Coal	Suspended solids	Other solid waste
Electricity	Total hydrocarbons	*Inc. landfilled*
	Mercury	*Inc. hazardous*
	Fluoride	
	PAHs (6 Borneff)	

(a) For external recycling and (b) for landfilling
(c) SPL = Spent Pot Lining
(d) Excluded from the IAI list but considered in this study

Table 2. List of considered Inputs / Outputs (as per IAI [4])

The model also took into account the environmental impact associated with material transport as well as the plant construction phase (use of construction materials). On the other hand, no impacts related to plant decommissioning were considered. Data corresponding to the actual operation of the plant were used (actual emissions, waste generation, etc.) when available, which was the case for most of the items. When specific data did not exist for this plant, values from comparable AP3X plants were used. In one instance (Water Polycyclic Aromatic Hydrocarbon – PAH – release), the average IAI 2010 LCI value was applied since no other relevant data existed.

As the main goal was to compare the intrinsic performance of the AP portfolio of pot technologies for a given energy block, two hypothetical plants operated in similar conditions (location, energy supply, material sources, etc.) and producing the same quantity of metal per year but equipped with different pot technologies (AP60 and APXe) were considered. Apart from the Electrolysis area, the other shops (Carbon and Casthouse) had similar technologies. When available, actual performance data (from the LRF prototype pots or the new Arvida AP60 Technological Center) were applied, extrapolated to account for a hot country operation. For items where no data were available, the reference case specific values were kept.

Main results

Figure 6 illustrates the relative contribution from each production area to the 4 criteria in the Reference (AP35) case. It shows that only a – still significant – fraction of the environmental impact associated with production of one metric ton of aluminum ingots is directly related to the smelter operation (contributions C+D+E+F), the rest coming from upstream processes (A+B i.e. bauxite mining and alumina refining), which is aligned with the conclusions presented previously in this paper. Indeed, upstream processes (A+B) account for between 10% ("Resources") to up to 55% ("Human Health") of the total impact.

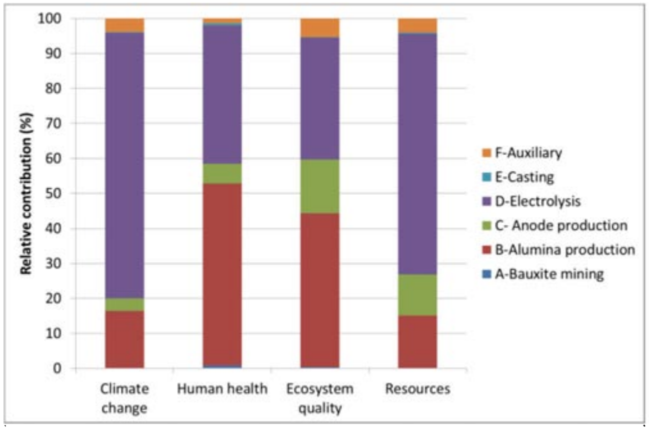

Figure 6. Relative contribution from the different sectors to each of the 4 indicators in the Reference (AP35) case

From a smelting technology designer point of view, the scope for reducing this contribution arising from upstream processes is limited and would result from a reduction in specific consumption of alumina from a typical 1.92tAl_2O_3/tAl to the minimum stoichiometric value of 1.88tAl_2O_3/tAl (-2%).

Focusing on the impacts from the aluminum plant (i.e. excluding upstream operations A+B), the Electrolysis sector is, as expected, by far the biggest contributor to the overall smelter footprint (60 to 90% depending on the selected indicator). Interestingly, the indirect impact from energy input is the biggest of all, in front of direct air emissions (refer to Figure 7). If this is no surprise for the Climate Change and Resources indicators, it was less expected for the other two and is accounted for by the emissions occurring at the power plant site. This energy-related contribution is, of course, highly dependent on the energy mix consumed by the plant or portfolio of plants considered. A smelter supplied by hydropower would have a very different profile on all 4 indicators.

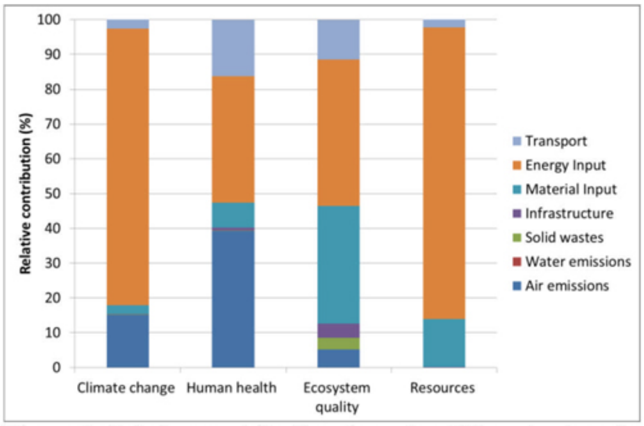

Figure 7. Relative contribution from the different categories of impact on the smelter global indicators (scope: C+D+E+F)

Furthering the analysis and excluding this "Energy" contribution, the majority of the "Human Health" impact relates to the "Air Emissions" category, which mainly includes the effect of particulates (PM2.5), sulfur and nitrous dioxides (SO_2 and NO_X) and Polycyclic Aromatic Hydrocarbons (PAHs). The "Ecosystem Quality" indicator is mostly impacted by "Material Input" (impact from coke, pitch and cathode block production), atmospheric emissions (sulfur dioxide and hydrogen fluoride), as well as the generation of hazardous waste. In this simulation, it was assumed that Spent Pot Linings (SPL) were entirely recycled; any alternative option would result in a significantly higher relative impact from the "Solid Waste".

When comparing the 3 AP pot technologies, Figure 8 shows how the different generations of cells have improved their environmental performance, from AP35 to APXe.

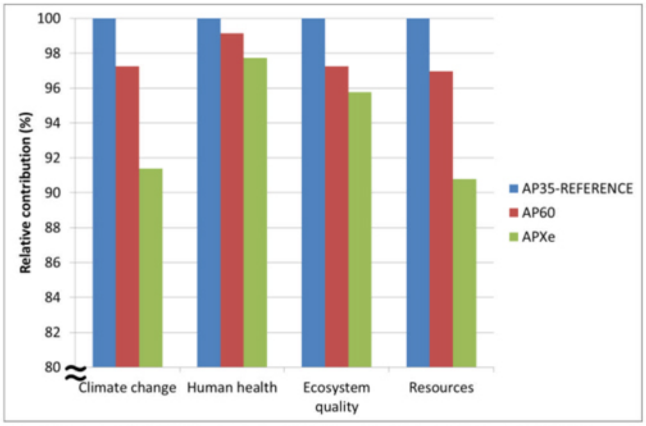

Figure 8. Relative comparison of the three different pot technologies

Most of the gain comes from the lower specific electricity consumption which, in turn, reduces emissions at the power plant site. Overall, this clearly reinforces the strategy aiming at low-energy cells. However, achievement of significantly less than 12.15MWh/tAl – the current APXe target – will require technological breakthroughs to be developed, and will thus take time. Any further medium-term improvement in the overall technology environmental footprint will therefore have to rely on other, less effective, technological levers as well as on an addition of small improvements on each indicator.

Discussion

With respect to "Climate Change" performance, ongoing development work is being pursued to minimize controllable emissions. The most recent generations of AP cells have benefited from the latest pot process control improvements, allowing for a drastic reduction in PFC emissions. Values corresponding to the lowest 10% percentile of the 2012 IAI Anode Effect Survey for Point Center Feed (PFPB) cells can now be typically achieved (<60kg/tCO_2-eq) [7]. Anode Effect Rates below 0.05AE/pot/day observed at the new Arvida AP60 Technological Center, which rates amongst the best industry performance, raise expectations with respect to the carbon footprint of this new cell technology [8]. To choose an example from the Anode Production area, new AP furnace designs using lower quantities of refractories will result in significantly lower specific gas consumption, estimated at around -20% compared to existing designs.

When combined, these opportunities could account for a further 50 to 100kgCO_2-eq/tAl reduction in emissions. Though relatively small compared to the average carbon footprint for the industry discussed above, it still makes for a significant absolute benefit once multiplied by a typical smelter aluminum production.

With respect to the "Human Health" and "Ecosystem Quality" indicators, these are still significantly impacted by direct air emissions. New cell generations are now intrinsically very efficient with respect to gas collection efficiency, and fluoride roof vent emissions below 0.20kgF/tAl are typically achieved on AP6X pots [8]. This contribution can be even further reduced by implementation of now mature technologies, such as Boosted Suction Systems or enclosed anode boxes [9] and scope for further improvement is limited. The focus will therefore switch to the remaining atmospheric pollutants.

The LCA approach is particularly relevant for analysis of impacts associated with pot linings. As discussed, the indirect impact from cathode production accounts for a significant percentage of the smelter "Ecosystem Quality" indicator (approximately 7% in the Reference Case). The effect of any change in design impacting pot life duration, and quantity or quality of the materials used can be assessed. Even more importantly, the impact of the different options for SPL disposal can be included in the analysis.

Overall, this analysis provides for an interesting new perspective, allowing for the relative quantification of the different sources of impact. As such, it should allow for more informed management of the environmentally-related portfolio of RTA R&D projects, also taking into account external impacts ("Material Input"). A model is now available within RTA, which allows screening LCAs to be rapidly conducted to assess any new design change. Future pot designs will benefit from this new approach, ensuring a continuous reduction of the technology environmental footprint.

Conclusion

Recognizing that Product Carbon Footprint (PCF) and LCAs represent strong market trends to which companies must respond to ensure long-term success, RTA has recently applied the methodology to assess the primary aluminum production environmental footprint, for its own benefit and as part of global industry initiatives, with a specific focus on Climate Change. As a next step, it is now collaborating with some of its customers by providing LCI data and LCA expertise.

From a technology perspective, while CAPEX/OPEX/FEC is the traditional way of comparing smelting technologies through cost comparison, LCA is a complementary assessment tool which may lead to a very different perspective. This innovative approach highlights efficient smelting process/technology features, which are not evident with a conventional economic comparison approach. A screening LCA model is now available within RTA, allowing holistic environmental assessment of future design changes, and thus ensuring a continuous reduction of the technology environmental footprint. This model will benefit from any developments in LCA methodology.

However, this methodology still has some limitations that must be kept in mind. First, the results are greatly dependent on the hypotheses used for modeling, such as the scope and the different databases. Whereas material and energy flows are, most of the time, relatively well-known, the scientific maturity of the impact factors is not as homogeneous. The industry should therefore continue to support the ongoing efforts aiming at continuous improvement of the methodology.

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