

## **An approach to a sustainable aluminium smelter design**

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### **Abstract**

When engineers start developing the concept of a new aluminium smelter, in many cases they look back at configurations that are used before or otherwise known. Local constraints and conditions are taken into account after which the design is optimized; however, this optimization is mainly done to save costs. In the future we should expect that new requirements will be introduced that will be part of the design process. One such requirement is Sustainability. With that is meant that the conceptual design of a smelter is such that it optimally uses resources such as energy and water, minimises air emissions and also applies a high standard of recycling and reuse of otherwise discarded materials. In this paper proposals are made to incorporate sustainable technologies, practices and other means of satisfying the sustainability requirement. An important starting point is that the integration of sustainability is achieved with no constraints of capital costs so that the creative process is optimal. The objective of this paper is to demonstrate that the design of a smelter can include a high degree of sustainable technologies and practices. These ideas then may be considered in future designs of new smelter projects.

**Keywords:** Sustainable development; aluminium smelter; design.

### **1. Introduction**

The design of aluminium smelters is considered to be optimized. It rarely changes dramatically if one takes a look at recent smelter designs. It goes back to the study phases of projects where engineers start developing the layout of a smelter. The layout changes depending on some local aspects but fundamentally there is not a lot different between projects. Also the choice of technologies within the design of a smelter is fairly standard. Whether it is a paste plant, a baking furnace or a set of potrooms, the technological choices are fundamentally the same.

Project development teams and engineers are pushed into corners where they are often not allowed to be too creative. Very often engineers go back to proven, but older designs rather than taking a fresh look at things. It must be recognized that projects are driven by capital costs and that owners, for good reason, drive this behaviour.

In this paper we want to focus on the sustainable design of a smelter. It involves introducing technologies and other aspects that would make the design of future smelter more sustainable, 'greener' so to speak. Some aspects that will be reviewed are readily available, while others still are ideas or need industrialization. This does not hold us back in considering it.

The purpose of the paper is an attempt to refresh everyone's thinking that we can do things different when it comes to the sustainable design of a smelter. Constraints such as capital costs may not lead to a full fledged roll out but by means of this paper we hope to establish a changing trend of including some of these more sustainable technologies and techniques in new smelter designs in the long term.

## 2. Boundaries

In our review we have to establish some boundaries so that it remains meaningful and to the point. It also keeps us focused on the main goal, which is to challenge the conceptual smelter design.

In our scope we consider the following:

- Port facilities for receiving raw materials and shipment of products,
- A carbon plant complete with storage, green anode plant, anode baking furnaces and rodding shop,
- A reduction plant complete with alumina transport, potrooms, and gas treatment centres,
- A casthouse with holding furnaces, casting machines and associated areas to make products ready for shipment,
- General areas for maintenance, administration and other supporting facilities.

This all forms the design of a modern smelter complex.

In the review we stay away from power generation. It has indeed a large impact on a smelter but there are different forms of power generation and also in different regions the approaches will be very different. So relative to the design of a smelter, it would make it more complex and the possibilities are enough for another paper. Therefore it is excluded.

In this paper we do not test any of the available technologies for sustainability whether this is for anode production or electrolysis, etc. This paper focuses on what else can be done or what general improvements can be made by all.

## 3. Considerations for sustainable design

Sustainable design is based on principles of sustainable development. This is defined in dictionaries in simple terms as “*economic development that is conducted without depletion of natural resources*”. To consider the outcome of the review to be sustainable, we have to follow some key guidelines that define sustainability. These are:

- Lower energy consumption and improved energy efficiencies,
- Reductions in the use of resources such as water or land,
- Minimizing air emissions,
- Reuse or recycling of discarded materials,
- Improved productivity (do more with what you have with lesser use of resources),

It is very clear that sustainable development is also economically driven and this is not forgotten, but for the purpose of the paper we place this aside in order not to slow down the creative process that we are after. All economic attributes will be taken into account when any sustainable design aspects are to be considered in future developments.

In the paper we will not specifically go into the social aspects that are part of sustainability; however, by considering the technologies and operating practices that are presented, the social aspects are positively impacted by default.

## 4. Carbon Plant

The carbon plant comprises the green anode plant (or paste plant), the anode baking furnace and the rodding shop. The following initiatives can lead to a more sustainable production of anodes for the reduction process:

#### **4.1. Alternative fuel for baking of anodes**

First, we consider the conventional anode baking furnace such as the open top type furnaces designed by AP technology or Riedhammer. The fuel used in the baking process is mostly natural gas. This is a very clean gas with moderate Green House Gas (GHG) emissions in the order of 300 kg CO<sub>2</sub> equivalent per tonne of aluminium [1]. However, in other cases fuel oil is used where natural gas is not available. The oil is a standard hydrocarbon based product.

Today, there are processes that convert wastes into biofuels. Progress is such that some of these fuels are very clean and sufficiently high heating values to replace in full or in part the standard oil. Because these are biofuels the GHG impact is positive. The overall GHG emission comes down by 20 to perhaps 60 % in case of a full replacement. Provided that the anode quality remains the same then this application of biofuels can create a win-win situation. The availability of biofuels in the right quantities and in the right place may today not be there yet, but technically it is certainly possible to see the introduction of biofuels in the near to medium future.

Another direction can be to use carbon containing wastes and gasify these into a fuel gas. This fuel gas can be supplemented to the fuel system in the furnace. This would involve transferring technology from other industries (power) to our industry.

#### **4.2. Alternative carbon sources**

Using alternative carbon sources that are derived from waste or is created in some sustainable way is of interest. It would introduce a GHG friendly carbon source that typically is also very low in sulphur.

Hydro Aluminium investigated the use of charcoal [3] a supplemental carbon source to make anodes. Charcoal is fine so it would replace a fraction of fine cokes. In the end the test results were negative as the anodes had lower apparent density and were more prone to high resistance and higher CO<sub>2</sub> reactivity.

Even though this result was negative, it does not mean there are other sources of carbon that have better sustainable attributes. Research should be continued in this area.

#### **4.3. Central VOC and PAH destruction with heat recovery**

In the green anode plant volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) are released during the production of the paste. At various points gas cleaning systems try to capture the fumes and remove VOCs and PAHs as best as is possible. Furthermore, fumes are released from the coal tar pitch storage facility when a truck or railcar is off loaded. There more often now thermal oxidizer equipment is used to destruct the VOCs and PAHs.

The idea can be to build one central regenerative thermal oxidizer unit in the paste plant to collect all VOC and PAH bearing fumes. These are destructed and the off gases are clean in nature. In fact, it will be possible to integrate heat recovery to extract some of the heat. Also, it is possible to return a part of the hot gases to the VOC/PAH pick up points where these gases are hot enough to prevent any of the VOCs/PAHs to condense into a sticky mass. The hot gases, laden with VOCs and PAHs, are returned to the regenerative thermal oxidizer (RTO) where the combustion takes place. Another approach is to recover the heat from the off gases in a heat exchanger and produce a hot liquid. This can be used as heating source in the paste plant.

#### **4.4. Integrate the Fume Treatment Centre into the Gas Treatment Centre**

In an effort to reduce the use of resources including land, the fume treatment of the baking furnace can be reduced by combining the fumes with the inlet gases to the Gas Treatment Centre (GTC) at the potrooms. It is not believed to save a huge amount of GHG or energy but it is a smart way to make use of processes inside the smelter. The GTC only needs to be nominally larger to treat the extra gases. This concept is readily available. It is successfully applied in the smelters of PNL Vlissingen (now defunct), Aluminium Bahrain and RTA Dunkerque [4]. The key is that should be considered in the design of a new smelter. The layout has to be created in a way that there is a short distance between anode baking furnace and the target GTC. It only requires one GTC to be modified and if the fumes from the bath plant are connected to the other GTC then both GTCs can still be designed for the same size.

#### **4.5. Vertical shaft anode baking furnace technology**

Perhaps one of the most promising step changes in the aluminium smelter can be the introduction of the vertical shaft anode baking furnace technology that is patented and developed by Lazar Anode Technologies. Rather than having the fires move through the furnace, the Lazar continuous carbon baking furnace (CCBF) technology uses a stationary process applied in a vertical shaft where the anodes slowly move from top to bottom.

It is well known that the mass of pitch fumes that is released from an anode during the heating stage holds enough energy to bake an anode. However, in the ring furnace the release is during short period of time and too short to cover the full baking cycle. This is one of the reasons that natural gas (or oil) is required as a fuel. Typically, the energy demand is 1.8 - 2.0 GJ per ton baked anode.

In the vertical shaft there is a zone where the anode reaches the temperature range during which the pitch is released from an anode. In this location a gas extraction system is integrated in the refractory wall that removes the pitch fumes from the shaft. Through a duct the fumes are drawn to the burners where the fumes are the fuel for baking the anode that is passing through the baking zone. This process is continuous which means that all the fuel to bake an anode is readily available in the form of pitch fumes. Only during start-up or upsets some natural gas is used as fuel. This means that an anode can be baked with virtually no external fuel input. There are some heat losses so a reasonable assumption that the energy use for external fuel is 90 % less than the total that otherwise would be used. In other words, this anode baking technology only uses around 0.2 GJ per ton of baked anode.

A further aspect is that the furnace walls are very well sealed. Only in one zone there are slots to extract the volatiles and everywhere else the bricks form a full seal. That means very little of the anodes and packing coke are lost in the process which results in further savings in GHG emissions as less carbon is lost in the process.

Lazar Anode Technologies has built a demonstration plant in Hawesville, Kentucky, USA. In 2014 and 2015 the plant received green anodes from Century Aluminium Hawesville and baked them into full size anodes. All anodes have been used in the reduction cells of the Hawesville smelter. This technology is not far from being commercially implemented.

#### **4.6. Hot anodes**

To reduce the energy requirements in a smelter one aspect can be to produce hot anodes rather than letting them cool down to ambient temperatures. When an anode is placed in a pot it draws valuable energy from the pot before it is at process temperature. Furthermore, when placed into

the bath the bath freezes on the outer surface because of the cold surface temperature. It therefore takes time before this layer disappears and during that time the contribution of the anode to the reduction process is very limited.

Any increased temperature above the ambient temperature will give energy savings and make the process more efficient [5]. The question now is how to keep the anode hot or how to increase the temperature?

One idea is to place the rodded anode into a chamber that preheats the anode. The heat is recovered from the process (can technically be anywhere; see also under heat recovery from the cell exhaust gases). Technically this is possible but logistically it is a serious challenge, lightly spoken.

The vertical shaft baking furnace (CCBF) offers the opportunity to remove the anodes earlier from the furnace and thereby keeping them hot. It will require a hot rodding process to keep some heat in the anode before it can be placed in a pot. That points in the following technical feature: on-time delivery of rodded anodes. This was discussed by Barry Welch [6] whereby the anode baking plant produces anodes that will be rodded and taken to the pots right away. A truly logistical balancing act to save energy. Not easy but it can be done if the setup is right.

Hot anodes bring new opportunities that need to be weighed against the logistics since there are so many anodes going through each day. So perhaps not today but who knows in the future.

#### **4.7. Anode cleaning shot blast waste**

In the rodding shop the spent anodes are cleaned in a shot blasting machine to remove the bath that is left on the anode but. In the process also some fine carbon is released due to the impact of the shot. In the end remains a waste product of iron shot, carbon and bath and this is very difficult to dispose of.

First, there are examples that this material is recycled with crushed bath. That by itself avoids the waste completely. However, the iron content will contribute to the iron levels in the liquid aluminium and if this is not in jeopardy with respect to the quality then this practice works well for a smelter.

Another inroad can be to agglomerate this material and establish a link with a steel company that uses the electric steelmaking (EAF) process with foaming slag. The iron reports to their product and the carbon is beneficial to the reduction process in the furnace. The drawback is the bath material that will report to the slag that floats on top of the steel. Some additional lime will be required to compensate for the fluoride and the residual calcium fluoride does shift slightly the composition of the slag, which normally is re-used as an aggregate. Overall, the expectation is that this can fit and become a good sustainable solution for it.

#### **4.8. Evaporation of waste water in Fume Treatment Centers**

In the fume treatment centre the fumes are cooled and conditioned by evaporative cooling. Water is atomized and sprayed into the fumes where the water completely evaporates.

There are cases where there is an excess of waste water. If this water cannot be recycled then in that case it can be evaluated if part of the process water supply to the cooling tower can be replaced by this waste water. There are some process requirements to ensure the spraying/atomizing system stays clean but if it is met then this waste water can be dealt with in

this way without having to discharge it. The net benefit is that the fresh water requirement is reduced and that special treatment can be avoided or reduced.

## **5. Reduction Plant**

In this section we list a number of opportunities in and around the potrooms. The focus is twofold: Reduce energy consumption by lowering the voltage drops and recovering heat from the process and make that available to the process in another way.

### **5.1. Measures and equipment to lower the energy consumption**

It is entirely possible to write a dedicated paper to what can be done inside pots to lower the energy consumption and reduce emissions such as GHG. But in line with the objectives of this paper we only list them and describe them in a qualitative manner.

#### **5.1.1. Copper inserts in cathode bars**

The current is withdrawn through the cell by the cathode collector bars. It is now becoming an accepted practice to use copper inserts to increase the conductivity of the bars and therefore lower the cathode voltage drop.

#### **5.1.2. Individual anode movement**

In traditional anode suspension systems, the anodes are clamped to a single anode ring busbar and using anode jacks, the anodes are collectively moved downwards or upwards to control anode-to-cathode distance and energy input to the cell. The downward movement also compensates for anode consumption.

The dynamics of the process leads to non-uniform anode current distribution, which contributes to the loss of process and energy efficiency. The control of anode current distribution requires the measurement of individual anode currents, which can be done in batch [7] or continuous monitoring mode [8, 9]. Eventually the anodes that carry too much or too little current are raised or lowered individually, using the Pot Tending Machine (PTM). This requires considerable potroom resources; therefore, only extreme cases are corrected.

Individual anode drives give additional means to the cell control system to further optimize the anode current control without manual intervention with PTM. They also assist anode setting, anode effect quenching and they eliminate the need for anode beam raising equipment [10, 11]. In this design, anodes are equipped with torque transmission means from normal anode jacks to the anodes to move anodes up or down in pairs or in group or in unison all together. The pairs of anodes are moved according to continuously monitored current distribution in the anodes [11].

The better control of anode current distribution should lead to lower energy consumption all together. A new study of how individual anode drives could be implemented at low capital cost, weighed against the quoted benefits should be undertaken.

#### **5.1.3. Anode current distribution sensors**

Recently there has been some further development on sensors for measurement of electric currents through individual anodes [8, 9]. Monitoring currents through individual anodes will lead to better understanding of some of the inefficiencies and dynamics in the process. It will enable maximization of cell stability, detection of adverse effects of spatial variations of anode current distribution, detection and prevention of anode effects and optimisation of operational

work practices. By enabling the control system to process individual signals, process improvements can be achieved that help lower the energy consumption further.

#### **5.1.4. Potshell heat recovery**

A large part of the heat that dissipates from a pot comes through the side walls. It is also a heat flux of interest because it comes through the side ledge that is important in the protection of the lining. Sidewall heat recovery helps controlling the side ledge thickness.

There are now technologies being developed that in one way or the other enable heat extraction from sidewalls and either capture it or regulate the heat flux in such a manner that it becomes beneficial to the thermal stability of pots. One example is the use of heat pipes [12] and another is the use of shell heat exchangers.

In a specific application the shell heat exchangers have proven to be very beneficial. During periods where the amperage through the pots was lowered, a reduction of cooling fan capacity lowered the heat flux and resulted in being able to maintain the bath temperature much better than otherwise is the case.

The challenge will be how to use this heat once it is recovered. Alumina preheating is definitely on the radar. So is the preheating of anodes [5]. Another approach is to convert the heat into electricity that can be used to drive some of the equipment. This can be by using organic Rankine cycle (ORC) machines or with new materials that convert heat directly into electricity. This is still all under development and it will still take some time before real economical solutions will be available.

#### **5.1.5. Bath sensing breakers**

Crust breaking is one of the most important operations in the aluminium reduction technology. The aim of using crust breakers is to break the crust which covers the centre channel of the cell between the anodes in order to expose the molten bath for the delivery of alumina. Problems in crust breaking lead to disturbances in alumina feeding, anode effects and a deterioration of cell performance. Intelligent crust breakers control the use of compressed air according to the pressure required on each individual break, which varies due to the local condition and properties of the crust at breaking point. This intelligence a large amount of compressed air and energy.

Bath sensing of crust breakers is one of the recent technological developments in control and reliability of alumina feeding [13]. Crust breakers with bath sensing give signals to pot control system (PCS) when a breaker tip touches liquid bath. Technical solution for bath sensing is simple – it only requires to detect a reliable electrical contact between the breaker cylinder rod and the bath when the breaker chisel touches the bath; the voltage between the top of the bath and a reference point on the cathode is used as feedback to the pot control system.

Bath sensing ensures that the breaker holes are open for unhindered alumina feeding and that the breaker does not stay in contact with the liquid bath and thus avoids problems due to breaker overheating, breaker wear and saves an additional amount of energy.

## **5.2. Other sustainable measures in Reduction**

### **5.2.1. Heat recovery from pot exhaust gases**

A number of years ago very few people would have been able to predict that in 2015 the first large scale heat exchangers would be installed in the collector ducts leading up to GTCs. But this is what has happened at Alba Line 4 [14]. There, eight individual heat exchangers have been placed into the off gas system by Alstom Norway. It opens up a myriad of new ways to use the heat that is recovered from the off gases. It also presents new opportunities to operate pots in a completely different way.

At Alba the heat is recovered in water, which is a dense medium so the heat can be transported to many places. While at Alba the heat is not (yet) used, it could lead to several technical developments that can make use of it. It must be pointed out that, yes, this concerns a lot of kilowatts of energy, but the temperature of the water is still below 100 °C so it remains low grade heat.

Irrespective, the heat can be potentially used for:

- Anode preheating,
- Alumina preheating,
- Production of electricity using ORC machines,
- Production of chilled water using absorption chillers,
- Heating of boiler feed water in the power plant.

### **5.2.2. Reduced pot exhaust flows**

In line with the previous item it is possible using the heat exchanger technology to deliberately run the pot exhaust temperatures close to 200 °C (assuming the superstructure is the limiting factor and can handle up to 200 °C). This is simply achieved by reducing the pot exhaust gas flow.

This is a double-edged sword because the increased temperature leads to much more usable heat once it is recovered, but the reduced flow also makes the filtration in GTCs requirements much smaller. Also the ducts become much smaller so there are considerable savings possible on resources too.

When the pot exhaust gas flow is decreased one can expect the concentration of HF to go up proportionally. But the mass flow remains the same and since the alumina flow is not changed there is enough alumina available to achieve proper scrubbing. More important is that the heat exchanger can reduce the gas temperature to 125 °C which ensures the scrubbing process is efficient and that no residual HF generation can take place on the bags.

Interestingly, the concentration of SO<sub>2</sub> also increases proportionally. This and the smaller gas volumes make it more cost effective to also apply SO<sub>2</sub> scrubbing if this becomes unavoidable.

One other important aspect to consider is the gas collection inside the pots. If the flow in a pot is reduced it means the under-pressure under the hoods decreases. If the gas flow would be gradually reduced then there is a point that the minimum gas flow is reached. Beyond this the gases start to escape from under the hood into the potroom. This minimum flow is a function of the under-pressure and of the hooding efficiency (in other words, how tight are the covers) so it requires operators to keep the hood in top shape with a very minimum openings.

This concept is a very different direction as to how we operate the pots today. But now we are struggling to deal with the temperatures as we raise the amperages continuously. Perhaps we have to give in to the higher temperatures and start making use of it rather than fighting it!

### **5.2.3. Minimizing fluoride emissions / Spent anodes**

Always high on the agenda is the reduction of fluoride emissions. The first question is if they can be avoided at all? But the answer is no because from the principles of fluoride generation some are integral part of the process (hydrogen and water in contact with bath). Therefore the focus is on minimizing the uncontrolled release of fluoride and on making sure it is scrubbed properly.

When an anode is removed from a pot, it fumes HF as the result of the contact between water vapour and the hot bath. These HF fumes disperse and are taken up by the air before it is discharged through the roof ventilator.

It is known that if the outer surface of spent anodes can be cooled to below 200 °C that the reaction of hot bath and water vapour is minimized. This led to the development of containers that contained the emissions and prevent air to get into contact with the anode but. Recently some refinements have been made and hopefully we will see more of this in use in potrooms all over. Only very few smelters have adopted the containers.

Another train of thoughts is to leave the spent anode for a day inside the superstructure to cool down before it is removed. The HF that is generated is also taken to the GTC in this concept. But it requires space above the crust and with the current hooding design that space is limited and in most cases not available. It will require a new design of the superstructure hooding but it may not be a very large adjustment. The factor that weighs heavier is that while the anode is hanging to cool, there is no anode in place to deliver the current at that location. The process can handle this because this happens anyways if a cold anode is placed, but it has to be carefully evaluated.

### **5.2.4. Minimizing PFC emissions**

PFCs are strong GHG gases that are produced in small amounts but have such a strong GHG intensity that they cannot be overlooked. We now know that PFCs not only are produced during anode effects but that there can be a constant PFC generation under normal process conditions. The best way to prevent the majority of PFC emissions is to ensure the alumina concentrations are above minimum levels in all locations in the bath. And if an anode effect occurs that this is killed as soon as is possible. This is now done by good pot controllers such as those from DUBAL.

However, there is more to learn about background PFC emissions that occur under normal conditions. For that we first need good continuous analysers that can directly measure PFCs in the gases. With those instruments process conditions and parameters can be linked to the response of PFCs. This hopefully will tell us how they are generated and what we can do against this.

### **5.2.5. Additional gas scrubbing**

#### **5.2.5.1. SO<sub>2</sub> scrubbing**

Still very few smelters apply scrubbing to remove SO<sub>2</sub> from the stack gases. It is mainly applied in Norway, Qatar and the UAE. But events in the markets for the supply of coke may change

this. Recently China adopted rules to avoid the use of high sulphur cokes in smelters which means the demand for lower sulphur cokes will further increase. On the other hand, governments continue to drive down SO<sub>2</sub> emissions and also the aluminium smelters are faced with this. Relatively, the smelter do not have a major impact with respect to SO<sub>2</sub> emissions but there will be a point that SO<sub>2</sub> scrubbing may be the better choice going forward.

What is to be hoped is that over time there will be SO<sub>2</sub> scrubbing processes available to us that minimize or avoid the use of water and produce a by-product that can be reused such as in fertilizers (ammonium sulphate) or building materials (calcium sulphate or gypsum). While these are already commercially used, none of them have been applied in aluminium smelters and that is a little bit different then otherwise is the case.

#### **5.2.5.2. CO<sub>2</sub> scrubbing/Carbon capture**

How smelters could apply carbon capture technology is explained in the 2010 TMS paper by S. Broek [1]. Today, this is not much different albeit the solvents used for CO<sub>2</sub> absorption have been improved. But from a cost point of view this still is a very expensive exercise and as long as other industries do not apply carbon capture on a larger scale, aluminium smelters will not use this.

### **6. Casthouse**

There are also some measures possible in the cast house.

#### **6.1. Prevent the forming of dross**

Dross is formed when aluminium reacts with oxygen from air when it is exposed during tapping or in the furnace. If the metal can be tapped in a closed environment and if the furnace can be kept closed at all times then the formation of dross can be minimized.

Electromagnetic stirrers (EMS) for furnaces: An EMS is based on the principle of a linear motor. A linear motor inductor is placed under or at the side of the furnace and a low-frequency moving magnetic field is generated when electrical power is applied to the motor. The metal movement is the result of the interaction between the magnetic field and the electrically conductive metal bath. EMS can significantly reduce dross formation in the furnaces. Dross is formed due to oxidation of alumina in presence of atmospheric oxygen. It increases rapidly at temperature above 775 °C. EMS can help in decreasing the temperature gradient by steering the melt resulting in lower surface temperature which will significantly reduce the surface oxidation and dross formation. It has other added advantages like Increased aluminium yield and decreased energy consumption. EMS is proven technology and available in the market as Air cooled Al-EMS and Water cooled Al-EMS system.

#### **6.2. Integrated heat recovery from furnaces**

A good practice that more and more is used is heat recovery from off gases from furnaces. There are already systems available that use the heat to warm up the combustion gases and this is savings on fuel and GHG emissions. This practice should be applied to all types of furnaces in the casthouse.

### **6.3. Re-use of cooling water**

Water is a scarce resource and should be managed properly. Cooling water should be treated so that it can be re-used in the casthouse or in other places in the smelter, even if this is in the FTC cooling tower where it can replace fresh water.

### **6.4. Unmanned vehicles**

Once the products are bundled and provided with the right labels, they are taken to storage areas waiting to be transported to customers. Recently, in this area unmanned vehicles have been introduced that handle all logistics of storage.

Automated guided vehicles are considered as very sustainable since they have life expectancy of 15 - 20 years compared to 5 - 8 years for regular transporters. They also require one third of the maintenance because they always run at their optimum design capacity. On top of this, they are electrical. One smelter received a GHG reduction subvention from the government because they replaced propane fuelled fork lifts by electrically driven fork lifts.

## **7. General areas**

### **7.1. Onsite integrated waste management facility**

There are several types of solid waste generated on a smelter site such as dross, SPL or shot blast waste. One thing that may help in processing them properly or to reduce their volumes is to develop an integrated waste management facility. This facility would hold special areas to segregate incoming wastes. This way some parts can be recycled directly in the production processes such as waste carbon. In addition, some intermediate processing is included to make the segregated waste suitable for use in another process such as waste-to-energy. Using such a plant it enables recycling of materials elsewhere or enables that separation can take place.

Another application within this facility is to crush and grind SPL prior to sending it to the end-processor, for instance to a cement plant. There are now examples that smelters grind SPL and ship this to cement plants. Also other end-users can be serviced this way.

### **7.2. Spent potlining (SPL)**

On average the smelter produces 20 kg of SPL per tonne aluminium and today it does that in two cuts: first cut with carbon and a second cut with the refractory materials. This material cannot be processed in the smelter so that it would be reused. The most sustainable solutions are found in the cement industries where the use of SPL has several positive contributions to the production of clinker. Other routes are using the BEFESA process, the Low Caustic Leaching and Liming (LCLL) process or the kiln technology of REGAIN. A comprehensive review of treatment, recovery and recycling of SPL is presented in [15]. Important is that the smelters look closely at what options are available to them, project that on regional constraints and apply a level of sustainability that ensure that whatever the outcome is, it is a solution that can be used for a long time.

### **7.3. Waste water**

There is waste water generated within the smelter. In some cases this can be transferred to a local waste water treatment plant but in other cases the smelter will have its own treatment plant.

A very sustainable practice is to use the treated water as irrigation water for grass, plants and trees on the premises. This displaces the use of fresh water and gives the smelter a very clean and natural look. This makes people happy!

More difficult is the water collected in the storm ponds. Because the rain water picks up fluoride from the roofs and equipment it holds a level of fluoride. Normally the water is left to evaporate so that net there is no emission.

There is technology to remove fluoride from water and it may be possible to apply this to storm water ponds. Then the water can possibly be used somewhere else in the plant. Even if this is to flush the toilets!

## **8. Conclusion**

The purpose of the paper is an attempt to refresh everyone's thinking that we can do things different when it comes to the sustainable design of a smelter. In the paper is presented a series of ideas, technologies and practices that can be considered when a smelter is designed or in part upgraded. Each item has a certain sustainability factor to it that – although we don't quantify this in the paper – adds to a higher level of sustainability. It is clear that in every area there are good opportunities to increase the level of sustainability. It is also clear that further research and development is needed to continue to enlarge the sustainability. We hope that some people be inspired with what is possible and start taking some of this into consideration in tier future plans.

## **9. Acknowledgements**

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