NATIONAL MAPPING OF SIDE STREAMS IN THE NORWEGIAN PROCESS INDUSTRY

REPORT PHASE 2
APPENDICES

APPENDIX 1

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APPENDIX 2.

RTC Ragnar Tronstad
2021-05-12

Carbon/quartz agglomerates for Si/FeSi production

During the last 50 years use of agglomerates in Si/FeSi production have been tested in order to improve raw material yield, and thereby improve cost position and/or environmental standards, but also as a method to reach improved furnace performance and for production of special quality products.
Development of agglomerate qualities are based on crushed and milled raw materials upgraded by magnet separation, flotation, use of special raw materials which is only available as powders, and also circulated raw materials and fines from coal/coke and quarts handling. In addition, a wide specter of binder qualities are tested and selected for the Si-quality to be produced. Examples from literature are pitch, dextrine, lime, gypsum, cement, bitumen, lignosulphonates, and if baking coals are used no addition of binder is needed. Further processing of produced agglomerates also depends on selected binder and can be drying, heat treatment, curing and others.
Exploitation of quartz fines for Si based smelting is to a high degree determined by the chemical composition of the agglomerates. Some impurities like Ti, P and B, are critical in produced Si/FeSi qualities and may limit the amount of agglomerates allowed in the charge mix. Other components may be reduced and accumulate at the furnace bottom, alkalis are reduced and evaporated causing condensation and degraded silica quality, CaO and Al_2O_3 will form slag and contaminate the Si quality. Some elements can be removed from the liquid Si melt by rather simple refining, while other impurities are more demanding and may need hydro metallurgical treatment and directional solidification to obtain in spec products.
The physical properties of agglomerates need close attention throughout the value chain from powder production to furnace tapping. Binders must have properties which maintain sufficient particle-particle strength to avoid fines generation during drying, heat treatment and its way through the furnace until it is consumed, or other mechanisms have taken over – like sintering, SiO condensation. Stoking is a common method to break up furnace crusts and force the charge towards the cavity around each electrode. Agglomerates is also exposed to this treatment and it is important to avoid disintegration and dust formation as this can cause extreme temperatures which will damage process equipment and give long production outages. These conditions are difficult to obtain in a small bench scale furnace where flow of materials and process gases are more favorable than in an industrial 3-phase furnace.
When chemistry and physical properties of agglomerates are according to demands it is demonstrated very attractive results from FeSi production at Holla, SiMn production in Brasil and also in Si pilot scale tests. Distribution of carbon and quartz particles inside the agglomerates and between agglomerates are most probably uniform. Segregation risk is therefore reduced by introducing stoichiometric agglomerates (2 mole C per mole SiO_2; $SiO_2 + 2C = SiC + 2CO$). Reaction rate is more rapid in agglomerates than in a lumpy charge, and Anders Schei et.al. has in the book «Production of High Silicon Alloys» documented the theoretical basis for expansion of the active zone in the furnace and how stoichiometric agglomerates influence power consumption in a positive direction. These effects are

observed in bench scale experiments (50-200 kW) for Si-production, but design of industrial furnaces is not yet optimized for agglomerated charges. However, tar bonded pellets charge has been tested in a 500 kW pilot furnace for FeSi production with promising results. During these tests it was also demonstrated that adding pellets to a furnace with bad operation conditions could more rapid be brought back to normal operation.
Another use of quartz-carbon agglomerates is to take a study carried out at University of New South Wales/University of Wollongong in Australia towards industrial scale. The study focused formation of SiC under different gas atmospheres and temperatures. Results from this work demonstrated an increased reaction rate potential by a factor 4. One by-product from this process was H_2.
In order to evaluate which by-products have potential for agglomeration and return to smelting furnace, more detailed analyses of chemical composition, particle size and distribution (PSD) are needed. Variations in batch-to-batch analyses will help for evaluating process robustness and the potential for making value of waste.

APPENDIX 3.

Memo

Expert Group – Hazardous Side Streams – SPL and Excess Bath from Al Production

Egil Skybakmoen, SINTEF

Introduction

Based on previous and ongoing projects we have made an overview and some thoughts and ideas for treatment of Spent potlining (SPL) and excess bath from the Norwegian Al industry.

Today the amount of SPL from the 7 Al plants in Norway is around 30 000 tonne per year. Globally it is estimated to be around 1,600,000 tonne per year. 20-40 kg SPL (avg in 2018 is 25 kg/tonne Al) is generated per tonne Al produced. SPL is divided into 1.cut (graphite/carbon part) and 2.cut (lining materials, linings and sidelinings).

The lifetime of one cell is normally from 4-8 years. In Norway around 350 cells are shut down per year. A challenge is the uneven wear of the graphite cathodes so a large part of the of cathodes is wasted. More than 50% of a graphite cathode ends as waste after a cell is shut down.

SPL treatment

Today the SPL in Norway is going to landfill due to classified as hazardous waste due to content of fluorides, sodium and cyanides. It reacts with water and formations of gases of NH_3, H_2, CH_4 and in some cases PH_3 occur. Storage and transportation are therefore also an important issue for safety. SPL is not homogenous. The amounts of infiltrated bath components are uneven distributed.

The main references in this memo are from "*H.A.Øye, S. Broek, "Formation, Characterisation & Treatment of Spent Potlining", Short course, Light Metals 2020, The Minerals, Metals & Materials Society, 2020 and "Sustainable Spent Pot Lining Management Guidance", World Aluminium, February 2020.*

It exists globally (but not in Norway) some established technologies to handle SPL is given in Table 1.

Table 1. Main technologies of SPL treatment without landfill.

Number	Technology	Usage / Product	Comments
1.	Grinding and pyrolysis, as fuel and additives for cement/clinker	Clinker and cement, steel, mineral wool	Na content a challenge and other raw materials used need to be low in Na. Not the case in Norway and Canada but OK in Middle East and other regions.

2.	Hydrometallurgical LCCL	NaOH (for alumina process), AlF_3, CaF_2, carbon products and for cement and steel.	Integrated with alumina and AlF_3 production. Capacity 100,000 t/year.
3.	Water addition + Heat treatment in rotary kiln.	Detoxify SPL 1.cut and 2.cut. Use gas as fuel in process	Regain: 3 SPL plants in Australia+ Bahrain? Can be placed near plants.
4.	High temperature rotary kiln	Detoxify SPL. Brick manufacturing.	Weston. Operate in Australia
5.	Cupola furnace with additives of basalt, slag and coke	Stone wool fibers, fines and dust to third parties	Rockwool, Germany.
6.	Salt slag mixing	Detoxify SPL – NaCl+KCl + Fluorides salts	Befesa Europe
7.	High temperature rotary kiln + addition of lime	Detoxify SPL and formation of CaF_2	Gum Springs. Give some landfill.
8.	Vacuum distillation at high temperatures	Pure graphite and fluorides.	Research in China and Norway
9.	Several other activities: a) The Orions Process. Rotary furnace. b) Plasma Vitrification c) SPL + NaOH	Glass product Cryolite, alumina	Canada. Pilot to be build. Tallum, Slovenia Engitec, Italy. Pilot 350 kg SPL/day to be developed.

According to IAI the application to cement represents 15 % of the total of 720 000 tpy in western smelters. In China it is estimated that 95 % ends up in landfill of around 1 million SPL tpy.

Ongoing projects with Norwegian partners to be mentioned:

Removal H2020 (2018-2022): One of 6 pilots will demonstrate the production of ferro-silicon from Electric Arc Furnace (EAF) co-processing of Bauxite Residue with other industrial by products, like SPL from aluminium production. Elkem, NTNU and SINTEF are Norwegian partners.
More info here: https://www.removal-project.com/

NoDeSPoL (2020-2022): Alcoa, Hydro, Swerim, SINTEF Helgeland and SINTEF Industry (their activity ended 2020). The aim is to purify the SPL with vacuum distillation at high temperature and use the graphite as a product. The evaporated bath needs to be treated further for eventually to produce AlF_3.

Some general comments for SPL treatment in Norway

The cost for SPL landfill solutions needs to be higher. Landfill taxes? Like in Switzerland. Then new solutions are developed. The cost will be considerable higher but new solutions may also give new business opportunities.

Some other remarks:

1. Collect all available information from Hydro and Alcoa regarding SPL treatments projects performed earlier and their strategy for the future. Bring NOAH in the discussions as well and others relevant stakeholders in this area (Stena, Ragn Sells etc).

2. New and better sorting technologies and procedures should be evaluated to extract the SPL in more categories (more than 1.cut and 2.cut).

3. Cost and technological solutions including sustainability should be addressed early in the project phase. An options analysis matrix should be made to evaluate the different possible solutions. Here we also should include "old ideas and projects" (like a process in Mosjøen by Johan A. Johansen as an example, Elkem SPL process in Bjølvefossen is another example). Should it be local solution at the Al plants? Or centralised?

4. Is it possible to use other waste to treat SPL? NaOH may be possible and should be evaluated (as proposed by NOAH expertise). This is also developed by Engitec, Italy. Worth to follow up!

5. Try to make new and more valuable products. This is the goal in the *NoDeSPoL* project for graphite products as well as fluorides. The fluoride components may be treated as excess bath (BADEland) for further production of AlF_3. Recently a paper was published where purified SPL was used as anodes for lithium ion batteries. Could this be an issue for future usage of graphite waste with increased usage of batteries?

   Ref: Zhao, Xin,Tian, Lai, " Graphitic carbon materials extracted from spent carbon cathode of aluminium reduction cell as anodes for lithium ion batteries: Converting the hazardous wastes into value-added materials", Journal of the Taiwan Institute of Chemical Engineers, 104 (2019, 201-209.

6. The Al producers should also continue to minimize the SPL amounts with higher cell life time and also new linings solutions. Rusal have developed some new technologies for re-use of recycling of SPL (RU-SLC Lining Technology). The carbon fraction of SPL replaces a part of the material in dry barrier mix. After use, 80% of the material is reused in the new lining. This concept is used in more than 1000 cells in Rusal.

   Ref: A. Proshkin et al, " Process and Environmental Aspects of Applying Unshaped Carbon Materials for Cell Lining Purposes", Light Metals 2021, pp 459-466.

Excess fluoride electrolytes from Al production

In modern aluminium production with prebaked anodes, additions of sodium oxide (Na_2O) from the raw material alumina are compensated by additions of AlF_3, causing a build-up of surplus electrolyte (often referred to as bath) in the aluminium cells. Further, the critical raw material CaF_2 is a key raw material in production of AlF_3. The excess electrolyte has previously been sold to new aluminium smelter and smelters with Søderberg technology. However, due to declining numbers of new smelters and prebake technology becoming dominant, there is a growing surplus of electrolyte in the market. Therefore, it is an increased interest to solve this challenge by Hydro and Alcoa in Norway and recently a project was established:

Recovery of valuable surplus bath components from Aluminium Electrolysis (BADEland):
Owner Alcoa Norway, Leader SINTEF Helgeland, Partners: Hydro, Fluorsid Noralf, SINTEF Industry, RCN financed Q3 2020 – 2023.

- The underlying idea is to retrieve AlF_3 from surplus electrolyte to reduce the use of virgin CaF_2 and avoid deposition of hazardous waste.
- This will be done by reaction with sulfuric acid (H_2SO_4) and aluminium hydroxide ($Al(OH)_3$) either directly or indirectly, in one of two processes. All process byproducts should be saleable.
- Pilot scale is planned in the end of the project.

Based on a present study in the SFI Metal Production, the two most promising routes for recovery of AlF3 from surplus bath seems to be either the conversion of fluorides to HF with sulfuric acid, similar to the current sulfuric acid route for producing AlF3, or the direct conversion using aluminium sulphate. A clear distinction between these routes is not possible without experimental proof of the concepts.

In Australia it is also focus in the same area and a company Alcore is recently funded. Here the target is to produce AlF_3 with waste products from both alumina (Bayer process) and Aluminium production as shown in Figure 2.

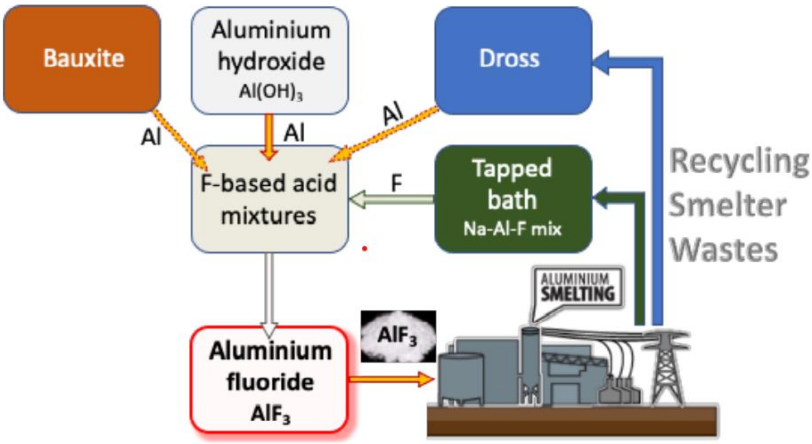


Figure 2. Alcore processes for AlF_3 production.

It will be interesting to follow both BADEland and Alcore approaches in the future. New technologies would help to at least to minimize the challenge with excess bath production and new methods to produce AlF_3 that the industry needs.

However, another option is to produce alumina with less content of Na_2O (today around 0.3 - 0.4 wt%) and thus reduce the build-up of bath during the electrolysis. However, this is said to increase the cost of the Bayer alumina process considerable and is therefore not an obvious option.

APPENDIX 4.

2021-05-18 Leif Hunsbedt, Eramet Norway

Hazardous waste / byproducts.

Some general considerations shared from a metallurgist who has worked for some decades in the borderline between production, R&D and environment within the production of manganese alloys.
In the following text byproducts are used as a general notation for all kind of waste, side streams and byproducts.

<u>Process issues.</u>

- An analysis of generation and recycling of wastes and byproducts has to be anchored in present production technologies. Emerging technologies and paradigms in in production technology will most probably be more focused on utilization og waste materials and energy.
- For the major production of metallurgical products in Norway the existing production technology will be maintained within a timeframe of 10 – 20 years. Accelerating measures connected to environment and climate change might occur, and might affect production technology, but no major changes of production concepts are seen in near future.
- The most obvious measure to reduce landfilling is to utilize waste materials into the original process, or into other processes. For this concept there are some key factors to keep in mind, from a process and environment point of view.
    - Some elements and substances might be harmful from a process point of view. As an example, in manganese production alkalis and zinc is harmful for the furnace process as these substances causes severe difficulties, and even hazardous situations might occur. Thus, it is desirable to get these substances out of the process loop.
    - For some elements the input must be controlled due to emissions. In manganese arsenic is such an element. If the input is too high, the following emissions to water becomes too high. Mercury is another similar element if cleaning on this element is not present.
    - Other substances might influence the properties of generated side streams. As an example, in the manganese production the addition of fluorides into the process causes harmful changes in properties of waste generated.
- For evaluation within each process one has evaluate the 'value in use' if a byproduct is recycled. The value might be represented by the specific element that is produced in each process, but other elements / substances might also be valuable. Virgin slag formers like quartz, limestone, dolomite and olivine might be replaced by using byproducts.
- Similarly, 'add on value' might also occur. In manganese production pilot trials are now being conducted with manganese sludge and dust from Si/FeSi production. The 'add on value' of the silica dust is connected to the ability to absorb moisture from the manganese sludge, making it possible to produce pellets for wet sludge.

<u>Cost issue.</u>

- In every recycling process it is the bottom line that counts. If a process isn't profitable it is difficult implement it.
- The cost is connected to investments and operating cost, often connected to logistics and processing of byproducts.

- The cost by recycling is related to an alternative cost, in most cases it has to be related to the use of virgin raw materials.
- Considerations regarding cost have to include future scenarios on different aspects. This might be taxes on landfill or on exploration of virgin raw materials. Another important factor is future cost connected to CO_2 emissions. Processes that might be non-profitable today might show another viability in the future. Thus, it might be wise to be prepared for changes in framework conditions.
- Of course, cost issues are a tool that can be handled by the authorities in different ways.

Logistics issues.

- One of the major problems with recycling of byproducts is connected to logistics challenges, and in the end again connected to cost issues.
- Some key factors here are:
  - Recovering of byproducts demands investment and operating cost for packing and transportation.
  - The volumes are normally in the small-scale end.
  - The distance between the producer and the consumer might be long.
  - Volumes and distance very often are in-between truck and ship transportation.
- A lot of byproducts are produced as dust / fines which in next step leads to transport challenges.
  - Previously a briquette facility was available in Grenland area.
  - Establishment of a new briquetting plant should be evaluated. Preferably a mobile unit.
- Thus, summarizing the bullets points under cost and logistics, use of virgin raw materials are normally more cost effective.

Industrial ecology.

- If recycling of byproducts is seen in a broader perspective, we have to include material and energy flow in the industrial system. We are then moving into industrial ecology and have to use another set of tools, including Life Cycle Analysis (LCA) and Material Flow Analysis (MFA).
- In this perspective sustainability has to be examined from different angels as technology, economics, toxicology, sociology, environmental science etc.
- This is a field of science which has been focused more extensively the last decades and has showed us that total accounting on this question is complex.

Regulatory issues.

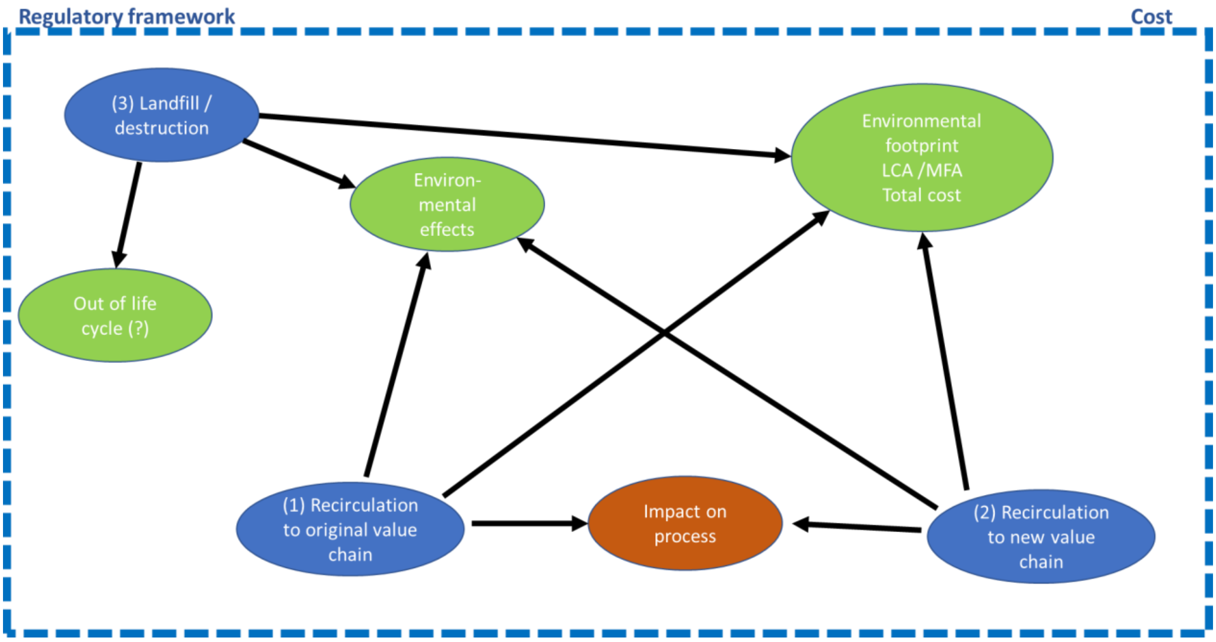
- Regardless of treatment the regulatory framework will apply either one chooses to recycle or not.
- If waste shall be recycled a special permission is required. Environmental regulation, as it is today, is not made for enhancing circular economy. Modifications can be made without compromising with environmental considerations.
- In general, environmental regulations should be revised to comply and support the green shift and circular economy.

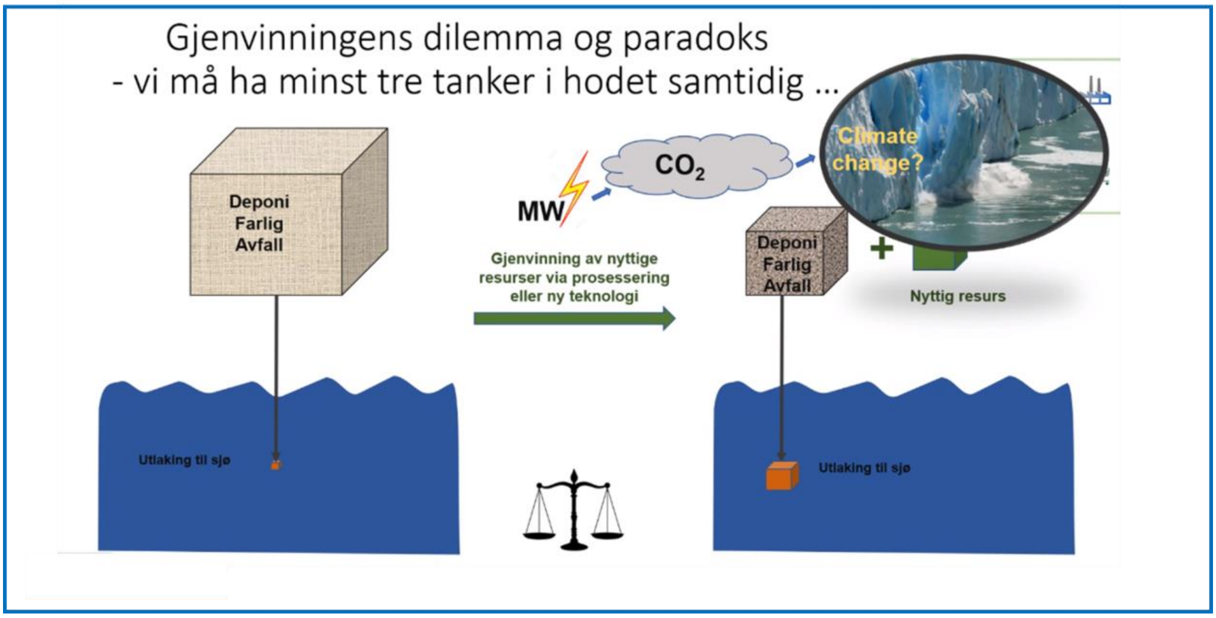
Kvinesdal 18.05.2021

Leif Hunsbedt

Attachments.

Possibilities for hazardous waste





APPENDIX 5.

COMMENTS TO SPL AND ELECTROLYTIC BATH,
BY Carlos Gago Rodriguez, Alcoa Europe
2021-05-25

Spent Potliner, also known as (SPL) is a waste that is generated at the end of the lifetime of the electrolytic cells used for the manufacturing of primary aluminum using the Hall-Heroult process. This waste stream is the consequence of cathode in the pot being spent. The new cathode mainly consists of carbon blocks and refractories. SPL intensity generation (tons of SPL per ton of aluminum produced) depends on various factors, including the type of smelting technology used (Söderberg vs prebake), pot and cathode design as well as raw materials used for cathode manufacturing, all of which impact the cathode life and eventually the SPL intensity generation.
In most European countries, SPL is considered a hazardous waste as per the applicable regulations. Additionally, due to SPL's water reactivity, the waste stream is also classified as a dangerous good for transportation (class 4.3), requiring specific conditions to meet Health, Safety and Environmental requirements. SPL basically consists of 3 main fractions: the carbonaceous fraction (first cut), the refractory fraction (second cut) and the interphase in between (see Figure 1)
Despite the fact that SPL is being generated since the beginning of the aluminum production in early 20th century, over the last decade or so most of the producers are actively working to develop outlets for beneficial use of this material and concomitantly attempting to reduce the amount of SPL being landfilled .
There is extensive number of bibliographic sources available that mention different options for handling, recovering and disposing the SPL in a sustainable manner. However only very few are currently in use today at an industrial scale. Several factors must be taken into consideration when selecting and deciding possible ways to handle this material in a sustainable and cost-effective manner:

- **The fact that the material is a hazardous waste:** This means that businesses interested in using this material must have an authorization as a waste disposer/handler.
- **The fact that the material is a dangerous good for transportation:** This means that special means and limitations for transportation exist and if and when feasible, it involves additional costs.
- **Transportation of SPL outside a country** requires export permits that are complicated from an administrative standpoint.
- **The size of smelters in Europe is in general mid to small and SPL generation per year is relatively small** making economics difficult for low volume generator. Economy of scale combined with proximity of SPL generation to end user is a relevant cost element to be studied in detail.
- **The Best Available Techniques Reference Document (BREF)** for Non Ferrous Metals Industry, published in 2016, suggests and identify some potential recycling routes (OJEU: Commission Implementing Decision (EU) 2016/1032; JRC, 2017)
- **Decarbonization agenda** in Europe will make recycling of carbon-based fraction of SPL that are used as fuels more complicated or substantially more expensive. In some cases, many of these potential technologies could be not implemented after electrification takes place.
- **Proximity to end use consumers of SPL** (first cut, second cut or mixed SPL). This could be a critical factor significantly impacting logistics…etc.

As mentioned before, a lot of research has been conducted with respect to potential beneficial uses of SPL. The International Aluminum Institute (IAI) has published a document summarizing the different options for sustainable handling and use of SPL (IAI 2020). Implementation and feasibility at a certain location or group of locations is highly dependent on the abovementioned points. There are several references in the literature about possible end uses of first cut and second cut to produce clinker and eventually cement. First cut is also used in some areas for steel production and mineral wool production (IAI, 2020). There are several other processes that are able to take and process the SPL to be finally consumed in different industrial processes, such as, Veolia US, Low caustic leaching / liming (Canada), BEFESA, Regain, Weston (IAI, 2020).

In addition to this there are several ongoing research projects, some of them in Norway: Alcoa, Hydro and GE works with the development of Vacuum distillation of SPL, with the intention to obtain recycling of graphite materials from first cut.

In summary, due to the relevant volumes of SPL being produced in Norway and the proximity to relatively other large producers not being able to recycle in country today, and considering the growing direction towards decarbonization and implementation of an actual circular economic strategy, SPL streams have enough criticality for a detailed review and update of different technical, environmental and business options in order to develop a sustainable and full recycling solution. It is recommended to develop the analysis also considering the trends in industry and environmental regulations and agenda trying to predict how the business model will be evolving from current situation to future scenarios.

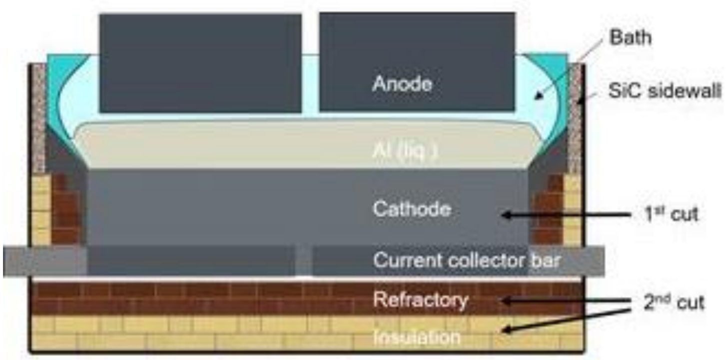


Figure 1. Cross section of aluminum Pot

Compound	Carbon Lining 1st Cut Range wt%	Refractory Lining 2nd Cut Range wt%
Al_2O_3	0-10	10-50
C	40-75	0-20
Na	8-17	6-14
F	10-20	4-10
CaO	1-6	1-8
SiO_2	0-6	10-50
Metallic Al	0-5	0
CN total	0.01-0.5	0-0.1
CN free	0-0.2	0-0.05

Table 1: Chemical composition of SPL first cut and second cut (Hydro Aluminium, 2018)

Table 1, cited by IAI 2020.

Bibliography:

- Sustainable Spent Pot Lining Management Guidance. Final. February 2020. International Aluminium Institute (IAI)
- Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries. Gianluca Cusano, Miguel Rodrigo Gonzalo, Frank Farrell, Rainer Remus, Serge Roudier, Luis Delgado Sancho. Joint Research Center. 2017.
- Official Journal of the European Union: Commission Implementing Decision (EU) 2016/1032

Electrolytic bath

“Aluminium is produced in the Hall-Héroult reduction cell where aluminium oxide is the raw material that is continuously fed to the cell and is reduced at the cathode, creating aluminium. The bath or electrolyte contains a mixture of cryolite (sodium hexafluoraluminate), aluminium fluoride and calcium fluoride. The ratio between aluminium fluoride and sodium fluoride in the electrolyte is of importance for the properties of the electrolyte. Aluminium oxide contains a small amount of sodium oxide, and when this sodium oxide is fed to the electrolyte, the chemical composition of the electrolyte changes over time. Aluminium fluoride will then have to be fed to the cell in order to maintain the correct composition of the electrolyte and this generates a surplus of electrolyte that will have to be removed from the reduction cell from time to time. This electrolyte can be sold to opening aluminium plants. For several years, the aluminium industry has expanded enough to absorb most of the surplus electrolyte, but this market is now reduced within the aluminum industry and there very few other relevant options in the market to absorb the quantities produced. Recovery options for these streams are important to avoid landfiling. Deposition is not a preferred solution for an industry working towards a more circular economy. In the **BADELand**[1] project (Recovery of valuable surplus bath components from Aluminium Electrolysis) research is being conducted to find an appropriate way to handle this waste stream.

Norwegian Research Council. BADELand – Recovery of valuable surplus bath components from Aluminium Electrolysis. https://www.forskningsradet.no/

APPENDIX 6.

Three successful industrial examples.

By Magne Dåstøl – former Director of Business Development at Elkem Materials
2021-05-24

There are some examples where quite heavy industrial emissions have been converted to successful business. Three of these are briefly described below.

- **Lignosulphonates (Borregaard).**

Lignin is the binding agent in wood and is extracted as lignosulphonates during the production of cellulose. For years, lignosulphonates represented a waste product, in Norway creating a significant pollution problem in the river and estuary of Glomma. Starting in the 1960-ies, by investing in an intensive R&D effort combined with investment in production equipment, the company managed not only to clean up the effluent, but also to create a completely new and profitable business based on lignin-based biopolymers derived from the former waste.

Today, lignin-based biopolymers are used in a wide range of end-market applications, such as agrochemicals, batteries, industrial binders and construction. Lignosulphonates are also the raw material for bio-vanillin which is supplied to flavor and fragrance companies, as well as to the food and beverage industry. These products have been commercialized in Borregaard's largest business unit BioSolutions, with production units in Norway, US, the Czech Republic, Germany and UK. Outside Norway, Borregaard has expanded this business to handle side streams from other pulping operators and converting it into profitable products. The company is a technology leader and the words largest supplier in lignin-based biopolymers as well as the world's only producer of wood-based vanillin.

Borregaard's biorefinery is an extraordinary cascading operation where wood, which consists of fibers, lignin and sugar, is turned into cellulose before the side stream from this operation is utilized for a variety of other valuable products. The side stream is first used in the production of bioethanol before the side stream from the ethanol operation is converted into lignin-based biopolymers.

Parts of the lignin are also used in the production of bio-vanillin and parts of the cellulose are converted into cellulose fibrils. Some side streams from production are also sold to other industries, which in turn use them as raw materials in their production. Knot pulp, which is removed from the cellulose and utilized for packaging materials and bark for soil conditioning, are examples of utilization of such side streams. The side streams that can't be utilized for products are converted into biogas or bioenergy used for energy in the production processes.

In Norwegian forest-based industries, the whole log of wood is utilized for products. The main driver for harvesting trees in Norway is wooden construction material. The most valuable part of the tree is used to make construction materials. More than one third of the wood entering the sawmill becomes residuals in the form of chips and sawdust. The remaining part of the tree and the residual wood chips from the sawmills are raw materials for Borregaard's sustainable, high value products.

- **Microsilica (Elkem)**

Norway has traditionally been a large producer of silicon and ferrosilicon. These are made in large electric smelting furnaces, at temperatures above 2000 °C, but create inherently a large amount of a silica fume ("microsilica") as a by-product in the form of a thick, white smoke. In the 1970-ies there were 11 such plants in Norway, with an estimated outlet of 150 000 tons/year microsilica – a substantial air pollution problem.

The extremely small microsilica particles (nano-sized), combined with high gas temperatures and - volumes, made filtering of the smoke a technical and economical challenge. In the mid 1970-ies, Elkem succeeded to develop an acceptable filtration technology, and in turn the Norwegian authorities imposed all (ferro)silicon plants to install filters. This created a business opportunity for Elkem, who started to sell the technology world-wide.

Successful filtration created a new problem, however: What to do with the microsilica? In the first years it was landfilled, but this clearly was not a sustainable solution. In 1980, Elkem established a separate business unit with the goal of developing products and sales of microsilica.

Around 300 possible applications were considered and partly tested. Of these, 20-25 were defined as "development projects" where quite significant R&D work were carried out. 6 - 7 of these areas became commercial application areas: Concrete, refractories, fibre cement (asbestos replacement), oil- and gas wells, fertilizers and plastics and rubber
More than 300 mill NOK was spent in R&D and business development before reaching break-even. However, the investment paid off, and by 1990 it had become a profitable global business. Elkem was sold out of microsilica and had started sourcing from external plants both in Norway and abroad. The moth-balled Meraker Smelteverk was re-started in 1991, this time to produce microsilica as a main product together with silicon.

Microsilica and spin-offs is today still a blooming business for Elkem, with sales to about 100 countries, and a number of sales offices and agencies abroad. Prestigious structures such as The English Channel Tunnel, The Storebælt and Øresund bridges in Denmark, the world's tallest building Burj Khalifa in Dubai, and the 32 km long East Sea Bridge in Shanghai were all built with microsilica from Elkem.

- **MOR-fume (Eramet Norway)**

MOR-fume ("Manganese Oxygen Refining") is a side stream from refining of molten ferromanganese. Oxygen is blown into a ladle to burn off undesired dissolved carbon, and during this process some manganese will be oxidized and leave the ladle in the form of a fine manganese oxide fume. Eramet Norway's plants in Sauda and Porsgrunn produce a total of some 30 000 tonnes/year MOR-fume.

In the early 1980-ies this fume was collected in a filter, pelletized with water and disposed of. The disposed material exhibited as a brown mud, with thixotropic properties when exposed to rain. It became clear this was an undesired way of treating the waste.

Chemical and microscopical investigation of the MOR-fume indicated a fairly pure manganese oxide in the form of Hausmannite (Mn_3O_4), consisting mainly of round particles of about 1 μm diameter, and with a high density (S.G. 4,7). It could be further refined by removing an undesired coarse fraction in a cyclone.

Further investigation indicated a number of potential markets for such a fume, and besides the plant's own staff the Microsilica Team in Elkem was given a role in product and business development. The fume was successfully sold to applications such as electronics (soft magnets), colour pigment for bricks and concrete, animal foodstuff, welding powder and micronutrients in agriculture. The business strategy was to diversify products and brand name them according to applications ("Elmax", "Colormax", "Agrimax", and "Weldmax").

However, a breakthrough took place with the development of the fume for use as a specialty weighting agent in oilwell drilling fluid and – cement ("Micromax"). The high density means it is suitable to control pressure in oilwells, and the small size and round particles mean little settling of particles ("sagging") and excellent flow properties. This application was at the time developed and marketed by Elkem and became and still is an international success. Today the global demand clearly exceeds the available production volume, in spite of sourcing for similar products abroad.

Indirectly this has led to a spin-off in the form of a novel weighting material – " Microdense" - a micronized ilmenite from Titania in Norway. The producer is Elkania DA, is a 50/50 JV between Elkem and Titania. Microdense is a complement rather than a competing product to the MOR-based weighting agent, but has been a success in the market place, and the company has plans to expand capacity.

APPENDIX 7

Livsløpsvurdering av miljø- og ressurseffektivitet og bærekraft for effektiv behandling av og utnyttelse av ressurser i sidestrømmer fra prosessindustrien

2021-05-25, Ole Jørgen Hanssen, Hanne Lerche Raadal (NORSUS)

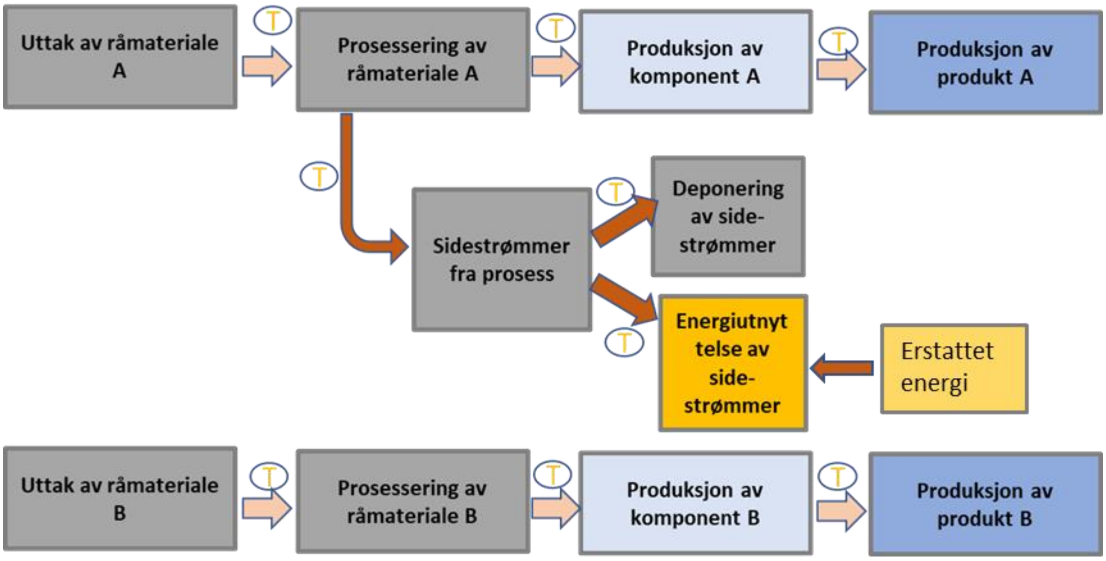
X.1 Introduksjon

Et viktig formål med prosjektet for å få oversikt over og bidra til bedre utnyttelse av sidestrømmer fra prosessindustrien, er å sikre mer miljø- og ressurseffektive og bærekraftige løsninger. Livsløpsanalyser (LCA) er en metodikk som er godt egnet til å analysere miljø- og ressurseffektiviteten av nye løsninger opp mot dagens måte å håndtere sidestrømmene på (Curran 2012, Christensen et al. 2020). I Norge har NORSUS utviklet modeller for analyse av netto klima- og miljønytte av ulike avfallstyper fra husholdningene som ble startet opp i samarbeid med Avfall Norge i 2008 (Raadal et al. 2009), og som har blitt videreutviklet til nye anvendelser innenfor biogass (Lyng et al. 2015 og Modahl et al. 2016), tekstilavfall (Lyng & Prestrud 2018), samt analyser av noen typer farlig avfall (lukkede rapporter). Modellene er analysert i et softwareprogram for livsløpsanalyser (SimaPro) og er basert på databasedata (ecoinvent 3.0) som det er tilgang til via SimaPro, kombinert med data for norske forhold (logistikk, behandlingsløsninger, avfallstyper og -sammensetning mm).
Ovennevnte LCA-modeller har hatt hovedfokus på klimapåvirkning og energibruk, mens noen modeller også inkluderer overgjødsling, forsuring og arealbruk. Andre typer miljøpåvirkninger som per i dag er mindre godt dekket opp i modellene er økotoksikologi og arealrelaterte påvirkninger som bla. biologisk mangfold. Dette vil det bli arbeidet videre med gjennom earthresQue-prosjektet (https://www.nmbu.no/tjenester/sentre/earthresque), som er et Senter for Forskningsdrevet Innovasjon (SFI). Her skal NORSUS videreutvikle modellgrunnlaget for flere typer relevante avfalls- og ressursstrømmer sammen med NMBU, NGI, NILU, NIBIO, IFE og BI i et 8-årig prosjekt. Her vil det også bli utviklet modeller for alle de tre dimensjonene av bærekraft, som inkluderer sosiale og økonomiske forhold gjennom livsløpet på samme måte som for miljø.

2. Modellgrunnlag for LCA-analyser av sidestrømmer

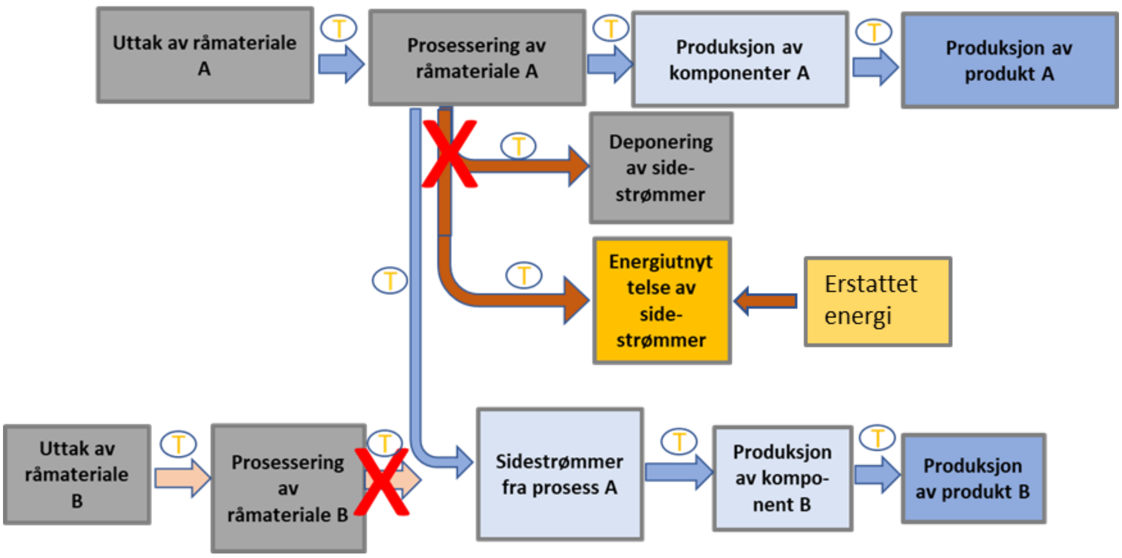
LCA-modellene som er utviklet for analyse av avfallshåndtering og som også er relevante for analyse av håndtering av sidestrømmer fra prosessindustrien, er basert på beregning av netto miljø/klima- og ressursnytte av dagens håndteringsløsning (referanse-scenario), sammenliknet med nye løsninger. I dette ligger at analysene beregner miljø- og ressursbelastning knyttet til transport og behandling av sidestrømmer/avfallsstrømmer fra de oppstår til de er ferdig behandlet og dermed kan inngå som resirkulerte material- og/eller energiressurser. Miljø- og ressursbelastningene kategoriseres som energibruk og utslipp til luft, vann og jord. Miljø- og ressursnytten beregnes deretter ut fra hvilket potensial de resirkulerte material- og/eller energiressurser har til å erstatte jomfruelige/alternative ressurser. Netto miljønytte beregnes som totale belastninger minus total nytte, og blir negativ dersom nytten er større enn belastningen.
Figur 1 viser typisk to systemer for produksjon av produkt A og produkt B, der sidestrømmer fra prosessering av råmaterialer til komponenter i produkt A genererer sidestrømmer som i basis-scenarioet ikke blir utnyttet som ressurs i nye produkter, men som går til

sluttbehandling enten til deponi eller til energigjenvinning. I modellen vil miljøbelastningen fra behandling av sidestrømmene avhenge av miljø- og ressursbelastningen til deponi og energiutnyttelse, samt hvilken energimiks som erstattes av energien som genereres av sidestrømmene. Videre sees at Produkt B produseres med basis i uttak av jomfruelige råvarer.



Figur 1 Modell for sidestrømhåndtering der ressursene ikke utnyttes, men går til sluttbehandling enten til deponi eller energigjenvinning

I figur 2 er det definert et nytt scenario med løsninger som innebærer at sidestrømmene blir håndtert som en ressurs som kan benyttes som råvarer inn i produksjon av komponenter til produkt B. Sammenliknet med modellen fra figur 1, vil man nå kunne analysere og sammenligne miljø- og ressurseffekten av at sidestrømmene, i stedet for å bli sendt til deponi-/energiutnyttelse, blir brukt til å erstatte råvarer til produksjon av produkt B.



Ved bruk av denne metodikken anbefales det å sammenlikne resultatene fra fremtidige anvendelsesområder for sidestrømmene med resultatene for dagens håndteringsmåte (referansescenario) for å vurdere om endringen resulterer i et bedre resultat enn nåværende løsning. I figuren over er referansescenarioet for sidestrømmene representert ved deponering og energiutnyttelse.

3. Bruk av livsløpsvurdering i videre prosess med utnyttelse av sidestrømmer

I det videre arbeidet med å øke utnyttelsen av sidestrømmer fra norsk prosessindustri fremover, er det viktig å gjennomføre LCA-analyser av dagens prosesser for behandling, som et grunnlag for å vurdere netto miljønytte av fremtidige løsninger. Viktige spørsmål for å sikre best mulig miljønytte og mest mulig bærekraftige løsninger på lang sikt som kan avklares i en tidlig utviklingsfase, er bla:

- Hva er netto miljønytte av dagens måte å behandle/utnytte sidestrømmene på?
- Hva er effekten på netto miljønytte av alternative løsninger (teknologiske, logistikkmessige, forretningsmessige)?
- Hva bør sidestrømmene utnyttes til for å få størst mulig netto miljønytte, dvs. hva slags ressurser bør de fortrinnsvis erstatte?
- Hva er effekten av å gjøre en sidestrøm om til et biprodukt?

Alle disse spørsmålene kan besvares dersom man har et godt modellgrunnlag og ikke minst har tilgang på data knyttet til energibruk og utslipp knyttet til alternative prosesser. I noen tilfeller er det en utfordring at data ikke er tilgjengelig for prosesser og løsninger som i dag ikke er utviklet og testet ut i praksis. I slike tilfeller må man basere seg på gode prosesskunnskaper og modellering basert på masse- og energibalanser.

Utover dette, er det også behov for å dokumentere hvordan miljø- og ressursnytten skal fordeles mellom produkter som bruker resirkulert materiale/sidestrømmer og produkter som tilrettelegger for at materiale/sidestrømmer kan brukes på nytt. Dette arbeidet bør kobles til pågående metodiske diskusjoner/prosjekter knyttet til bruk av LCA-metodikk (Ekvall et al., 2021, Swedish Life Cycle Center, 2021), og vil gi danne grunnlag for hvordan resirkulering og økt utnyttelse av sidestrømmer vil påvirke miljøprofilen både til produkter som genererer biprodukter/resirkulerte råvarer og produkter som tar det i bruk.

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APPENDIX 8

Overview of webinars, workshops and podcasts

Type	Title	Purpose	Organizer	Date	participants	
					N	Org.
Webinar	Material side streams and opportunities	Information, collaboration, and contacts	The project and Eyde-Cluster	Feb. 11th	45	Eyde members, research organizations, recycling business, universities
Webinar	Information about the material side streams	Information, collaboration, and contacts	IGT and the project	Feb.	20+	Process industry in Grenland
Webinar/ meeting	SFI Metal production, spring meeting	Information, collaboration, and contacts	SFI Metal production	April 20.-21	100 +	Norwegian Process Industry plus research institutes and academia
Webinar	Process 21 and mapping of side streams Norwegian Process industry	Information, collaboration, and contacts	ASM Finland	April 20th	50+	Materials-centric engineers and scientists
Webinar	Material side streams and opportunities	Information, collaboration, and contacts	Avfalls-forsk, Avfall Norge and Eyde cluster	May 7th	30	Recycling industry, Eyde-cluster
Webinar	Waste streams with potential for value creation	Information, collaboration, and contacts	Avfalls-forsk, Avfall Norge	May 21st	39	Recycling industry, Eyde-cluster
Webinar	Material side stream mapping, special emphasis on hazardous waste	Information, collaboration and contacts	Norwegian Environment Agency	June 1st	70	Recycling Industry, public representatives
Work-shop	How to connect future recycling needs and material side	Collaboration and in put to the work and the recommandations	Avfallsforsk, Avfall Norge and Eyde cluster	May 28th	7	Eyde-cluster, recycling industry

	streams from the process industry					
Webinar and work-shop	Process 21: The development of entrepreneurship, products, and the supplier industry	Information, collaboration, and contacts	Eyde Y	April 29th	10	Universities, Eyde-members
Podcast	Podcast about the material side stream mapping. Gunnar Kulia fra Eyde-klyngen og Jorunn Voie fra Elkem - Sirkulér | Acast	Information	Avfall Norge, the podcast: «Sirkulèr”	May		
Podcast	Podcast about circular economy and industrial symbiosis. Sirkulærøkonomi og industriell symbiose - Sirkulér | Acast	Information	Avfall Norge, the podcast: «Sirkulèr”	May		