# NATIONAL MAPPING OF SIDE STREAMS IN THE NORWEGIAN PROCESS INDUSTRY

## REPORT PHASE 2

PREPARED BY
Gunnar Kulia, Jorunn Voje, Tonje H Salgado, Stine Skagestad, Helene Fladmark, Magne Dåstøl, Ole Jørgen Hansen, Stein Espen Bøe and Karsten Rabe.

APPROVED BY THE STEERING COMMITTEE MAY 2021

Due to the participation of international experts in the process, the chosen language is English.

# 1. Executive summary and recommendation

## Introduction

In July 2020, the Norwegian Ministry of Climate and Environment appointed the Eyde Cluster to conduct a mapping of material flow analysis for the Norwegian Process Industry with the purpose of increasing resource efficiency and reduce waste from the industry.  The Norwegian Process Industry has been a driving force to develop environmentally friendly and sustainable solutions, with a clearly defined goal to be world leading in resource and energy efficiency.  A road map to become $CO_2$- negative re emissions by 2050 was presented in 2016, and Process21 had clear recommendations to facilitate for circular economy thinking and solutions in the recommendations to the Government presented in February 2021.

The work has been conducted in two phases.  During Phase 1, delivered in December 2020, more than 90%, 54 of 58 invited companies, participated in the mapping, sharing information about all important side streams of materials from their companies. And in total, data for 249 side streams were collected.  The data has been organized in a database, and Power BI is used for presentation on aggregated or detailed level.

The work has been planned and developed in close cooperation with partners: Industrial Green Tech (IGT), Norwegian Centre for Circular Economy (NCCE), Arctic Cluster Team (ACT), Avfall Norge (AN), Process21 and the Federation of Norwegian Industries (NI) have together with Eyde Cluster all been represented in the steering committee. ACT, NCCE and IGT have also named representatives to the project organization, where experts from SINTEF and NORSUS have been actively involved.

A reference group with participation from process industry companies, competence suppliers, catapult center and research institutes, has been consulted on a regular basis.

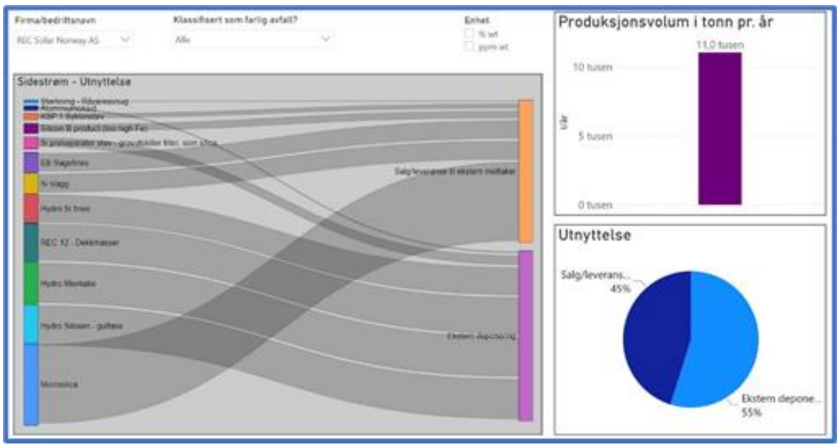


*Figure 1: Data with side streams from one company, illustrated in Sankey diagram.*

For further information on Phase 1, reference is made to the report “Nasjonal kartlegging av materialstrømmer fra prosessindustrien” published in December 2020.

## Phase 2: Preparing for usage of the data

Phase 2 is a first study of the collected data. This report covers the work completed by June 1st , 2021. Many of the participating process industry companies have already developed circular and new value chains for products based on what was previously waste. This project is built on experiences from previous work, avoiding focus on areas that are already covered in a good way through other initiatives. The main focus was on

- Working with complementary group of experts,
- Open Innovation activities, and.
- preparation for future use of the database.

### *Expert groups (Chapter 2)*

Three expert groups were invited to participate in the process, two for non-hazardous and one for hazardous side streams. Each group consisted of 4-7 experts, representing market, potential technology suppliers, universities and research institutes – both Norwegian and international experts taking part in the process (see list in appendix no 1). Normally, it takes at least 3 -5 years to develop a new market potential. The 5 months' time frame only allowed us to make recommendations for further work. However, through 2 meetings in each expert group and individual preparations prior to these meetings, the goal to present at least 4 -5 ideas for further development work was reached. We recommend readers to go through the propositions for hazardous and non-hazardous waste presented in chapter 2.

One important learning of this process is the value of putting together interdisciplinary expert teams, - and in particularly mixing national and international experts. The scientific community in Norway is competent, however, sometimes a bit too small. Using the international, interdisciplinary expert group in this project has brought new knowledge and ways of looking at the material and possible solutions. We recommend to continue using the established network in the future work.

Another appreciated learning is the positive feedback from the participating companies, both in collecting the information about the side streams and in the evaluation phase. The companies positively engaged in technical discussions regarding possible solutions, realistic or not. This engagement is and was of outmost importance.

### *Open Innovation (Chapter 3)*

In the open innovation process it has been important to share information about the projects and attracting actors that might have solutions for utilizing the side streams and have ideas for collaborations. Open minds, competence, knowledge, connections, and match making were the key words in this process.

The process involved a range of individual meetings with companies, entrepreneurs, clusters, and market organisations in order to explore new markets, opportunities and to connect across traditionally "segment-borders". The mapping and the ongoing work have been presented in several webinars (also internationally) and in podcasts, with the purpose of informing a broad audience about the mapping, and reaching out to actors that might be interested in participating in the process. Digital workshops have been organized to explore new markets and/or to get input on the ongoing and further work with the material side streams. These activities have resulted in contact with actors who might have solutions for better utilization of the material side streams. We have identified several other initiatives promoting circular economy thinking nationally, indicating a need for further cooperation and to coordinate our efforts.

### *Database (Chapter 4)*

The database has been developed through insight from the collected excel sheets. Based on the information given in the sheets and knowledge from the experts, the database has been designed to a more standard data format. The positive effect of standardization of the data is better analyses and comparison of information. Data and information shared from companies to the side stream data base is the property of the companies where the side streams originate. The steering committee decided that the project needed input from all parties in the process of giving recommendation for the future management, usage and development of the established database. To conduct this mapping and analysis the project chose the consultant firm AS Boldt, who has broad knowledge of the process industry. Their study was conducted April-May.

## Recommendations

Conducting a mapping of side streams and by-products in the process industry was one of the main recommendations from the Process21 expert committee on circular economy (august 2020). This work will contribute significantly to an even more circular process industry, and is a starting point for the collaborating platform for the companies to move forward.

### *Platform for collaboration*

The parties participating in the collecting of the data are eager to move forward in a partnership to establish a robust organisation to managing, using and developing the infrastructure for sharing data according to the findings and recommendations given by the informants in the BOLDT report. There are both judiciary and financial issues to discuss, and the parties hope there will be interest from the government side to finance this further work.

In addition to the development of and maintain the infrastructure itself, the following recommendations about needed collaboration activities came up through the process:

- Exploring markets, users, combination of side streams and be a connector and accelerator between the companies.
- Continue using interdisciplinary expert teams in these processes - in particularly mixing national and international experts.
- Arenas for sharing knowledge – both within the same industry and across industries
- Continue raising awareness and knowledge about what it takes to go from a linear to a circular economy both for companies and the government.
- Continue learning and connecting to other countries (i.e. The Netherlands) and markets.
- Map side streams from other industries
- Facilitate workshops for open innovation
- Facilitate for openness about data and opportunities

These activities are in the very early phase of an innovation process, where neither market nor a clear business idea is identified. Therefore, both the further development of the collaboration infrastructure and the co-creation activities will need co-financing from the Government. Existing programs that might fit for this purpose is Norwegian Innovation Clusters (Innovation Norway), Norwegian Catapult (SIVA). ENOVA might also play a role – due to earlier experience of financing network for reduction of energy consumptions.

### *The Government's role in enhancing the development towards circularity*

The participating companies are eager to follow up on the possibilities identified in the process, but there is a need to understand and to resolve some of the obstacles to succeed. The process has given some insights in line with Process21 and other recommendations given by the industry to the Government's strategy on circular economy. These are outlined below.

As described in detail later in this report, cost, technical limitations and regulatory restrictions are often barriers in work to develop circular economy solutions, even if possibilities are identified.  Transportation needs, energy or other resources required to create circular value chains, also need to be carefully evaluated to make sure that solutions are objectively environmentally friendly.

On the other hand, customers expecting circular solutions can be a driving force in market transformation. Through the process of identifying markets for the identified side streams, we have been aware that, although there is a lot of discussions on circular economy, markets for industrial solutions are still immature. This may be due to regulatory constraints, but more often the projects are not commercially viable.  We expect that policy shifts and EU's new Taxonomy instrument will bring new dynamics into parts of these markets, but there is also need for incentives and positive policy measures to enhance a circular economy:

### *Developing the market*

The Government and other public institutions could play a major role in developing a market for products with less use of resources through **Public Procurement**. This is especially relevant for material side streams identified in this mapping. By demanding a percentage of waste material in building constructions, road construction etc, the branches will be driven to set standards and thus elaborate the markets.

Public procurement should be followed by **a revision of regulations** to comply and support the green shift and circular economy. Environmental regulations, as functioning today, are not made for enhancing circular economy. Modifications should be made without compromising with environmental considerations.

### *Reducing risk*

As described in the report the issue of cost and risk for the companies' engagement in projects regarding circular economy is different from other development project. The risk could be linked to undeveloped markets, being a first mover, and not only technology challenges. Co-development between companies cross industries where the economical gains of a project could be challenging to identify, is often the situation. The existing public innovation agencies and their programs are not set up to meet these challenges and a change is needed. Existing programs, e.g. “Miljøteknologiordningen” (Innovation Norway), ENOVAs and the Research Council of Norway’s Innovation Program have their focus on technology readiness level and revenues, and projects to enhance resource efficiency rarely meet the criterias. Programs where the criteria of gaining increased resource efficiency are needed (E.g. the way ENOVAs program for energy efficiency used to work).

# 2. Use of experts to identify potential new value chains

## 2.1. Introduction

Phase 1 of the project “Mapping of side streams from Norwegian Process and Mineral Industry” resulted in an overview of 249 side streams reported back from 54 of the larger Norwegian industrial enterprises (96% feedback). Details about volumes, chemical compositions, physical state, hazard classifications and current utilizations have been registered in a searchable data base, Microsoft Power BI, designed for further processing. Phase 2 is a first study of the collected data. Three expert groups have been appointed; one in non-hazardous side streams, one in hazardous side streams and one open and very interdisciplinary group. The first group, non-hazardous side streams, and the “open innovation group”, were challenged to discuss potential utilization of the different streams. The group on hazardous side streams were, according to the guidelines from the Ministry, to discuss minimalization and possible treatment of the hazardous streams in order to minimize deposits.

## 2.2 Methodology

The three appointed expert groups consisted of participants from research institutes and universities, from the process industry itself, from the market and from suppliers of different technical solutions, totally 4-7 persons in each group. Interdisciplinarity has been a key factor for the groups. It has also been important to look outside of Norway in order to get a wider perspective of the work. Relevant European competence centers have been invited to take part in the expert groups. Appendix no 1 gives an overview of the experts participating in the process.

Each of the groups got a list showing the side streams to be studied and evaluated. The list included the name of the side stream, the tonnage per year, the three main chemical components and comments regarding particle size and particle morphology.
Company name was omitted.
This information is not sufficient to be able to do a complete evaluation of the materials and suggest satisfactory solutions. For doing this, more details are needed, like full chemical analyses. The devil is often in the details. However, ideas and suggestions for solutions are anyhow possible. And if the company owning the side stream find the idea of interest, more information will be exchanged. Two meetings for each group have been held and quite a lot of informal discussions in between the meetings. After the expert meetings, the incoming ideas were presented and discussed with the respective owners of the side streams. If a company found interest in a potential solution, the company representative and the expert were coupled and discussed how to proceed.

## 2.3 The outcome of Phase 2.

The outcome of the work is divided into non-hazardous and hazardous side streams.

*The Non-Hazardous side streams:*

About 152 non-hazardous side streams were registered in phase 1 of the project. The annual tonnage is roughly 10,2 million tons, and varied from some 100 tons per year for the smallest stream to about 5 mill tons per year for the largest. About 65 streams were selected for the further evaluation. The criteria for the selection were focusing on the largest streams and looking for possible short-term solutions. Longer term solutions are, however, also discussed in form of 3-4 years projects.

Some 80 proposals/ideas on possible ways of using/treating the selected side streams were registered. The ideas are a mix between totally new ways of looking at the streams and ideas that are building on old knowledge and existing markets, but anyway shows a potential for the material stream. The experts, even if their background is totally different, tended to focus on more or less the same side streams. This underlines the potential of these side streams. However, all proposals will be archived for later use.

A selection of the most discussed cases is described below:

<u>Dust streams and fines:</u> There are several dust streams from the metallurgical industry. This is in particular carbon dust from the aluminium industry and radiclone dust from the silicon/ferrosilicon industry, with a total amount of 20 000 tons per year. Likewise, are there about 200 000 tons per year of quartz fines from quartz mining and from the silicon/ferrosilicon industry. If dust and fines from the mineral industry are included, the total amount of these types of side streams are about 360 000 tons per year.
The metallurgical industry aims at reusing as much of the side streams as possible. However, today, lots of tons are deposited due to lack of technology introducing fine material to the furnaces. At the same time much of the material, especially the carbon dust, contains unwanted impurities and has to be refined before returned to the process.

Research has been done over the years on how to cope with fine materials. According to former R&D Director at Elkem Solar (now REC Solar) Ragnar Tronstad, over 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. Tests have demonstrated that by adding agglomerates/pellets to a furnace with bad operation, the process could be brought back to normal operation more rapidly.
For more information about carbon /quartz agglomerates for Si/FeSi production, see Appendix no. 2.

<u>Metallurgical slags like Silico-Manganese slag:</u> Three metallurgical plants in Norway are reporting a total of 420 000 tons per year silicomanganese slag. Current uses are mainly for landfill, roads, asphalt, and raw material for cement clinker production. However, the production is currently exceeding sales volumes. More recent research indicate that slag may have a potential also as a replacement for fly ash in cement (SCM), as a partial cement replacement in concrete and as soil amendment in agriculture. Currently, two concrete

producers are testing the material on industrial scale. In the short window the market may be limited to use in non-construction concrete since this type of slag is not (yet) prescribed in cement- and concrete standards. Longer term it may be possible to achieve a technical certification or apply for modification of the current standards. The use in blended cement or concrete may lead to a quite significant reduction of $CO_2$-emission compared with current practice, thus indicating a future increased value.

<u>Mineral side streams like anorthosite and different tailings:</u> The amount of such side streams are huge, totally close to 9 million tons per year.
Geopolymer concrete use alkali-activated aluminosilicate minerals as a binder instead of Portland cement. Some side streams from Norwegian mineral industries such as anorthosite, norite or feldspars may have a potential use in this application. It is claimed that geopolymer concrete may reduce the $CO_2$ emissions by more than 70-80% compared to traditional cement-based concrete. In Norway, the company Saferock plans to start a pilot operation based on norite, a side stream from ilmenite production, as raw material. Lack of standards may at least short term limit the market, for example for construction concrete.

For overburden in mining (the material that lies above the material to be exploited), side-rocks, off-grade minerals and metallurgical slags there may be a potential use as concrete aggregates, in road construction, for landfilling (cover), ballast and in asphalt. The market potential is often limited by the costs for crushing, sieving and logistics, and hence confined to use in the local market. However, high quality rocks (mechanical strength, abrasion resistance) may have an export value for use as concrete aggregates.

<u>Electrolysis bath:</u> There are more than 10 000 tons per year of excess electrolysis bath from the Norwegian aluminium industry. The reason for this is that in modern aluminium production with pre-baked anodes, additions of sodium oxide (Na2O) from the raw material alumina are compensated by additions of AlF3, causing a build-up of surplus electrolyte; often referred to as bath, in the aluminium cells. Research Manager at SINTEF Industry, Egil Skybakmoen, continues: *"Further, the critical raw material CaF2 is a key raw material in production of AlF3. 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 a cooperation project led by SINTEF Helgeland was recently started".*
In Australia it is also focus in the same area and a company Alcore is recently funded. Here the target is to produce AlF3 with waste products from both alumina (Bayer process) and aluminium production. *"Another option is to produce alumina with less content of Na2O (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"*, Egil Skybakmoen concludes. For more information about electrolysis bath and projects, see Appendix no. 3.

*The Hazardous side streams:*
About 97 hazardous side streams were registered in Phase 1. The yearly tonnage is roughly 730 000 tons and varied from some few tons to 300 000 tons for the largest stream.
Landfill is today the most common solution for hazardous side streams.

About 64 of the streams were selected for further evaluations. The selection was based on the same criterias as for non-hazardous side streams, - focusing on the largest streams and looking for possible short-term solutions. Longer term solutions are also discussed in form of 3-4 years projects.

Some 40 proposals/ideas on possible ways of using/treating the selected hazardous side streams were registered. The ideas are, as seen in non-hazardous side streams, a mix between totally new ways of looking at the streams and ideas that are building on old knowledge and existing markets, but anyway shows a potential for the material stream. Also here, the experts tended to focus on more or less the same side streams, which again underlines the potential of these side streams. It should, however, be emphasized that finding a proper solution for hazardous side streams is complexe. There are several factors involving environmental issues, regulations and standards that should be taken into account.

A selection of the most discussed cases is described below.

A general comment from former Technical Director at Eramet Norway, Leif Hunsbedt, is that 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 environmental 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 cause 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 become 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.

It is always important to evaluate the “value in use” of the recycled material. 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 side streams.

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.

However, in every recycling process it is the bottom line that counts. If the process isn´t profitable, it is difficult to implement, Leif Hunsbedt concludes. See also Appendix no 4.

<u>SPL /Spent pot lining from the aluminium industry</u>: Spent Pot lining is a waste that is generated at the end of lifetime of the electrolytic cells used for manufacturing of primary aluminum using the Hall-Heroult process. This waste stream is the consequence of pot cathode 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 different factors: technology used (Söderberg vs prebake), pot and cathode design as well as materials used for cathode manufacturing, all of them impacting the lifetime of the cathode and eventually the SPL generation ratio (intensity).

Today the SPL in Norway is going to landfill due to classified as hazardous waste because of high 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.

The Norwegian "production" of SPL comes from the 7 Al plants (Alcoa and Hydro) and sums up to around 30 000 tons per year. Globally it is estimated to be around 1,600,000 tons per year. 20-40 kg SPL (avg in 2018 is 25 kg/tons Al) is generated per ton Al produced. Environmental Manager, Carlos Rodriguez Gago, from Alcoa Europe and Egil Skybakmoen, Research Manager at SINTEF Industry, have given valuable input to the challenges and the future regarding SPL. They both refer to possible technological solutions used elsewhere, outside Norway. As the reuse of SPL or parts of it, - as the aluminium company Rusal are working with. Other potential solutions are extraction of the graphite part of the SPL for other purposes like anode-graphite in Li-ion battery, or as some aluminium companies are working with, try to minimize the SPL amounts with higher cell life and also new lining systems. Another mentioned step is to put landfill taxes on SPL, like in Switzerland, to force increased activity on finding solutions. Ref. Appendix 3 and 5.

There is an extensive amount of work done on SPL involving recycling, reuse and chemical treatments to reduce or remove hazardous elements. Projects have been going on for the last 50-60 years. Over those years, however, a lot has changed regarding technical solutions and new production methods. As Mr. Gago from Alcoa states, *"considering the growing direction towards decarbonization and implementation of an actual circular economy strategy, SPL streams have enough relevance for a detailed review and update of different technical, environmental and business options to develop a 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: 5, 10, 20 years from now".*

<u>Diluted acid:</u> This side stream originates from production of $TiO_2$ pigments and sums up to about 300 000 tons per year. The diluted acid is based on sulfuric acid but also contains some other elements, mainly non-hazardous. Parts of the side stream is today recycled, and the rest is deposited at Langøya (NOAH).

Karl Kristensen from Bergfall Environmental Consultants has commented that the diluted acid could have other options. Because the waste acid does not contain problematic levels of heavy metals or other hazardous compounds, it could potentially be recycled into new products like commercial grade gypsum for use as plaster boards or as additive in cement production, or other sulphate containing chemicals, including ferrous sulphate and ammonium sulphate.

Potential use of the diluted acid for gypsum production is confirmed by Head of Innovation, Morten Breinholt Jensen, at NOAH. Dr. Jensen states that the commercial value of gypsum is limited, as gypsum is available in abundance as a product from desulfurization of flue gas from coal-fired power plants (FGD gypsum) and from natural occurring gypsum rocks. However, as Europe is shifting towards a carbon-free energy production, the gypsum prices are expected to increase somewhat in the future as low-cost FGD gypsum is vanishing from the marked. Calculations and experiments indicate a potential of an annual production of 65 000 tons “white gypsum” and 20 000 tons “red gypsum”, respectively. The “white gypsum” can serve as raw material in plaster board production or in the cement production, while the “red gypsum” can be landfilled or applied as material in road construction or similar.

Mixed residue from zinc production: There is a mixed residue coming from zinc production with a yearly tonnage of some 160 000 tons. Today’s solution is landfill in mountain caverns. Karl Kristensen at Bergfall Environmental Consultants has commented on this residue that considerations should be done on extracting one or several of the components in the residue, including both thermic and hydro-metallurgical recycling methods. The company owning the side stream have been informed about the thoughts from Bergfall.

## 2.4 Key learnings

One important learning from evaluation of the side streams using expert groups is the value of putting together interdisciplinary expert teams, - and in particularly mixing national and international experts. The scientific community in Norway is competent, however, sometimes a bit too small. Using the international, interdisciplinary expert group in this project has brought new knowledge and ways of looking at the material and possible solutions. We recommend to continue using the established network in future work.

Another appreciated learning is the positive feedback from the participating companies, both in collecting the information about the side streams and in the evaluation phase. The companies positively engaged in technical discussions regarding possible solutions, realistic or not. This engagement is and was of utmost importance.

However, as former Director of Business Development in Elkem Materials, Magne Dåstøl states; - the discussion between the reporting companies and expert teams have revealed several factors that may be influential to realize potential projects. Some of these are:

- *Competitive cost.* Cost is clearly one of the most decisive factors to establish a circular use of materials. Even relatively marginal cost differences may become project stoppers. Taxation or fees on disposal and/or use of virgin raw materials are tools that may catalyze and enhance circular economy. However, taxation/fees are very sensitive ways of regulating disposals etc, and may put an extra burden on the companies in question.

- *Technical limitations.* In particular two factors have been mentioned, (1) too large quality variations in the side stream, and (2) the challenge of improper sizing, in particular related to utilization of fine materials. There may be techniques to overcome both of these challenges, both for smoothening and levelling quality variations, as well as agglomeration techniques to utilize off-grade fines materials. Thematic webinars drawing on industrial practice from experienced companies may be considered.
- *Cost of* $CO_2$*-emissions.* There is a current proposal from the Norwegian Government to gradually increase the $CO_2$-taxation for the non-quota sector up to 2000 NOK/t by 2030. Some of the reported side-streams may become useful tools to reduce this emission, for example slags, fly-ashes and certain minerals. It is suggested to look closer into these opportunities, including bureaucratic regulations that today may hamper or block realization. An example is use of silicomanganese slags reported from three plants, which may give a theoretical saving of more than 200 000 t $CO_2$-/year if used for cement replacement in concrete, or as filler in cement (SCM).
- *Regulatory restrictions*. Sometimes utilization of side streams is reported to be hampered by formal regulations, “rule by the book”, rather than physical realities. Examples have been given for use as soil amendment, liming in agriculture, for landfill, disposal coverage, for use as pozzolanic material in cement and for aggregates in road construction. Thus, to enhance circular economy, there may be a need to discuss these issues with the relevant authorities.

Despite all the discussions regarding possible solutions, it is, though, important to keep in mind that it takes time making “gold” from a “waste”. There are several success histories over the years, like the Microsilica story in Elkem, where a waste stream from the furnaces ended up as a valuable component in concrete, refractories and ceramics. During production of silicon and ferrosilicon, which is done in large electric smelting furnaces, at temperatures above 2000 $^{o}$C, a large amount of a silica fume (“microsilica”) in the form of a thick, white smoke is formed as a bi-product. 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. At the same time, Elkem started an extensive R&D work to find possible utilization of this new powder. Which resulted in several application areas as mentioned. For more information about Microsilica, see Appendix no 6.

Other examples are how Borregaard created business out of the waste product lignosulphonate. 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. For more information, see Appendix no 6.

A third examples of successful utilization of a side stream/waste is how Eramet Norway turned business out of a fume coming from refining of molten ferromanganese. This fume, which is a result from oxygen blowned into a ladle to burn off undesired dissolved carbon, is called MOR-fume (Manganese Oxygen Refining). Eramet started to collect the fume in a filter in the early 1980-ies. After some hiccups in the start, investigations showed a number of potential markets for such fume and Elkems Microsilica team with their experience in developing Microsilica was asked to contribute in the product and business development. The fume was successfully sold to applications such as oil- and gas well drilling, electronics (soft magnets), colour pigment for bricks and concrete, animal foodstuff, welding powder and micronutrients in agriculture. Of these, the sale to oil-and gas well drilling has increased significantly the last years. For more information, see Appendix no 6.

## 2.5. Circular economy and the essence of sustainability

Recycling of "waste" and side streams are essential in the circular economy. As it is in the process industry. Alcoa, one of the worlds largest aluminium producer focus on reuse of their side streams. But as Process Development Manager at Alcoa Mosjøen, Ellen Myrvold, states: *"As the world strive to find solutions to go from the linear into the circular economy, the good intensions can make us blind to the purpose of the task, namely to make the production, use and reuse of materials and energy sustainable. As the policy makers as well as the consumers and stakeholders rightfully demand the industry to find circular solutions for the waste, there are some fundamentals that tend to get lost.*
*A circular solution is not necessarily better for the planet, if the Recycling of it is making the energy and chemical consumption of the system rise to unhealthy levels, the economy of the solutions will never be good, and you create new waste stream that will also need solutions. Using industrial waste materials as fuel to processes that can be electrified is such an example. In most cases the waste will take the energy consumption of the combustion up as they contain "waste" as well as reducing agents. The combustion process will be less effective and the* $CO_2$*-emissions higher than necessary. True circularity comes from understanding the total picture from cradle to the final grave, including the use and reuse of a material. This might sound all-consuming and make the burden of recycling heavier, but the point is after all to use less, and if you can't identify true savings, the equation will never add up".*

Former Technical Director in Eramet Norway, Leif Hunsbedt, focuses on cost issue regarding recycling. If a process isn't profitable, it is difficult to implement. The costs are connected to investments and operating cost, and to logistics and processing of byproducts. Considerations regarding cost have to include future scenarios on different aspects, like taxes on landfill or on exploration of virgin raw materials. Another important factor is future cost connected to $CO_2$- emissions. Non-profitable processes 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 can be handled by the authorities in different ways.

Another important issue is logistics. 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.

Thus, summarizing all this, use of virgin raw materials are normally more cost effective. There are also 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*", Leif Hunsbedt concludes.

## 2.6 Life Cycle Assessment

Life cycle assessment (LCA) is a methodology that is well suited to analyze the environmental and resource efficiency of new solutions against the current way of treating side streams. There are many players specializing in doing LCA both nationally and internationally. In Norway, NORSUS, Norwegian Institute for Sustainable Research, are one of them. NORSUS have developed models for analyzing net climate and environmental benefits of various types of wastes and side streams. The figure shows how secondary resources (ex. side streams) can be utilized as input and a replacement for raw materials in a process.

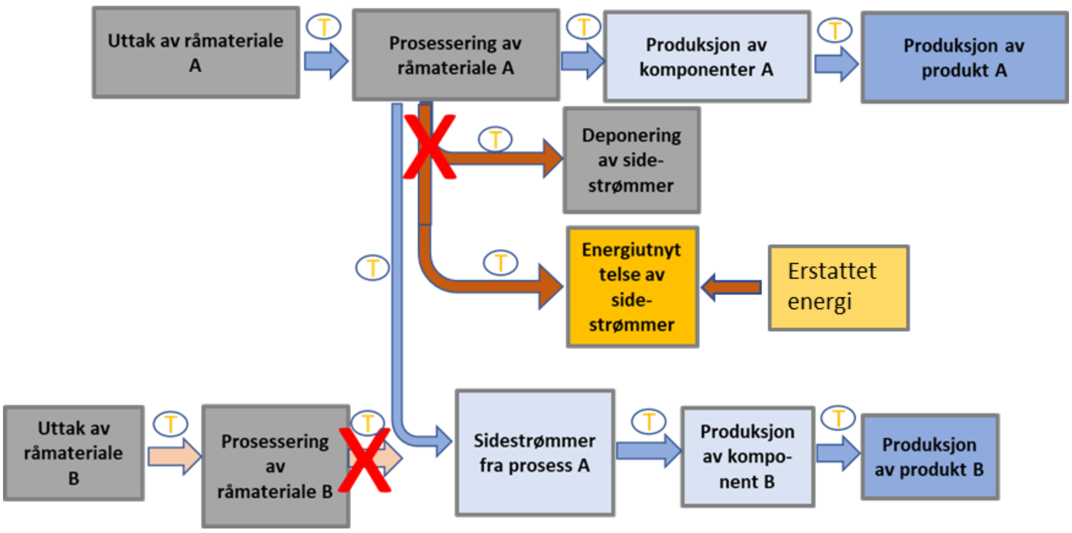


*Figure 2: Model for side stream treatment where the resources are used as input in production of new products (NORSUS, see Appendix no 7).*

As pointed by both Ellen Myrvold at Alcoa and Leif Hunsbedt at Eramet, it is important to get an overview of the net environmental value gained in introducing a side stream into a production process. According to Senior Research Scientist, Ole Jørgen Hansen at NORSUS, *"Important questions to ask is what is the net environmental benefit of today's solution of the side stream, what is the effect of alternative solutions, how and where should the side streams be used and what is the effect of turning a side stream into a bi-product*". For more information about LCA, see Appendix no 7.

## 2.7. Recommendations – how to proceed

We will recommend to continue the started/on-going discussions on some of the side streams with the companies owning them. There are several ways of doing this; informal discussions, small pre-projects or larger projects. There will be need for public finance in this process. The potential solutions vary in terms of maturity, need for development and number of companies with interest in the solutions; some will have international interest, and there is a possibility to look to the EU for partnership and financial support.

### *For Non-hazardous side streams:*

<u>Dust streams and fines</u>

Fine material, dust or powder are not easily recycled or deposited. It has to be processed in some way or another like briquetting or pelletizing. Combinations of two or three type of powder materials may give interesting and beneficial "products" for reuse, or combining one powder with another type of side stream like a sludge could also give "products" that more easily can be reused in the process. These are examples of ideas/projects started and tested years ago for some type of materials, but which has been revitalized and looked upon with new eyes and also new type of side streams during this project. Eramet is a company heavily involved in such projects. We urge them to continue the started work, which we think they will.

<u>Metallurgical slags</u>

Particular silico-manganese slags are of interest. This slag may have a potential as a replacement for fly ash in cement (SCM), as a partial cement replacement in concrete and as soil amendment in agriculture. As described earlier, two concrete producers are currently testing the material on industrial scale. In the short window the market may be limited to use in non-construction concrete since this type of slag is not (yet) prescribed in cement- and concrete standards. Longer term it may be possible to achieve a technical certification or apply for modification of the current standards. The use in blended cement or concrete may lead to a quite significant reduction of $CO_2$-emission compared with current practice, thus indicating a future increased value. These are also ideas/projects started outside of this project; however, the side stream mapping has revealed other metallurgical slags that might have the similar effect. We recommend to contact those companies.

<u>Mineral streams</u>

There is a huge amount of mineral side streams, bi-products and tailings like 9 million tons per year. Discussions with the Finnish R&D institute VTT made us aware of the opportunities of a new concrete quality called geo-polymer. Geopolymer concrete use alkali-activated aluminosilicate minerals as a binder instead of Portland cement. Some side streams from

Norwegian mineral industries such as anorthosite, norite or feldspars may have a potential use in this application. It is claimed that geopolymer concrete may reduce the $CO_2$ emissions by more than 70-80% compared to traditional cement-based concrete. In Norway, the company Saferock plans to start a pilot operation based on norite, a side stream from ilmenite production, as raw material. The largest "producers" of such side streams are made aware of this opportunity and are coupled with Saferock.

*For Hazardous side streams:*

SPL from the aluminium industry.

Spent Pot lining is a waste that is generated at the end of lifetime of the electrolytic cells used for manufacturing of primary aluminum using the Hall-Heroult process. It sums up to about 30 000 tons per year and is today going to landfill. A lot of R&D work and testings on SPL have been going on for decades. Some solutions are used today, abroad, however, not implemented by the Norwegian aluminium industry. On the other hand, some of the national projects resulted in technical solutions, though not implemented, mainly due to cost and that landfill was much cheaper. However, especially use of landfill is about to change and taxes might come. We believe this might open for a review of earlier projects and technical solutions. We therefore recommend to finance a project to go through all former work done on SPL, both national and international projects.

Diluted acid

This side stream originates from production of TiO2 pigments and sums up to about 300 000 tons per year. The diluted acid is based on sulfuric acid but also contains some other elements, mainly non-hazardous. Parts of the side stream are today recycled, and the rest is deposited at Langøya (NOAH). There are several comments on exploiting this side stream. Production of gypsum is one suggestion and we support to investigate this further.

Then there are some 240 more side streams that might have potential for further processing and recycling. This project was too short to start a process evaluating all of them. But we hope that "a spark is lit" for looking into them as well.

# 3. Open innovation

## 3.1 Introduction and methodology

In the open innovation process it has been important to share information about the project and attracting actors that might have solutions for utilizing the side streams and have ideas for collaborations (see list of participants in Appendix no 8).

Open minds, competence, knowledge, connections, and match making were the key words in this process. There has been many one-to-one meetings with companies, entrepreneurs, clusters, and markets organisations in order to explore new markets opportunities and to connect across traditionally "segment-borders". Going from a linear economy to a circular economy, demands a broad view on your own production, including the entire life span, and there is a need for collaboration in new ways.

## 3.2 Description of activities

### *Webinars and podcasts*

The mapping and the ongoing work have been presented in several webinars and podcasts, either arranged by the project, in co-operation with other, or by invitation; e.g two of the podcast episodes at the "Sirkulèr"- podcast by Avfall Norge have been dedicated to this project. The main focus in all webinars and podcasts have been to inform a broad audience about the mapping, describe the side streams on a generic level and describe the methodology for innovation and success stories from earlier and ongoing work. It was important to reach out to actors that might be interested in participating in the open innovation and the expert groups.

### *Workshops*

All the workshops have been digital due to the Covid 19-restrictions, arranged either by the project or in co-operation with interested parties. The purpose has been to either explore new markets and/or to get input on the ongoing work on the side streams. All participants have been eager to explore the data in more detail and are impatiently waiting for the further life of the database. The recommendations from the participants are listed in the last section in this chapter.

## 3.3 General reflections about the open innovation

The webinars, workshops and podcasts have resulted in contact with actors who might have solutions for better utilization of the material side streams. All ideas have been registered. Some of the contacts have already led to interesting investigation in sides streams, others are a confirmation of ongoing work, and a third category must wait with the further investigation until the ownership and management of the data and the database is established.

Another important part of the open innovation has been to investigate and establish contact with markets and niches. The focus has been on construction, aqua/fish/seafood, and soil improvement/fertilizer. The main learning is that the markets are still quite immature regarding circularity, but the willingness to work across traditionally markets and niches are present. Direct contact between entrepreneurs and process industry companies have been established as a result of these processes.

There is a shared recognition of the need for action to strengthen the "green shift" through the entire society and the upcoming demand for more circular products. The companies closest to the customers seem to have the best knowledge about how to perform LCA, and update the Environmental Product Declaration (EPD). ESG, LCA, EPD, EU Green deal, industrial symbiosis and circular economy are buzz words that some seem to know well, and have started implementing in their business, while others are still mixing the terms. More knowledge about LCA, EPD, the requirements in EU Green Deal, and the opportunities in an industrial symbiosis is necessary and would help many companies.

### 3.4 Recommendations – how to proceed

One barrier in the work done in phase 2 has been the limited use of data. A formalisation and regulation of the use of data as described in chapter 4 will solve this issue and the future process of open innovation will be easier.

*The recommendations are:*

- Financial support of projects that are not typical research projects: Now the needs are mainly collecting the low hanging "circular fruits" through collaboration activities. The former funding program by Enova used to work very well for projects regarding energy efficiency projects based on a "need to know" application, with little bureaucracy. A similar model for funding would make the shift from a linear to a circular economy faster.
- Keep exploring markets, users, combination of side streams and be a connector and accelerator between the companies. An overall knowledge is important to perform well.
- Knowledge sharing - within the same industry and across traditionally "borders".
- Raise awareness and knowledge about what it takes to go from a linear to a circular economy in all companies, among the authorities, and the government.
- Learn from other countries (i.e. The Netherlands) and other markets.
- Openness about data and opportunities is essential.
- Collaboration when it is possible, and compete when needed.
- Continue mapping side streams from other industries in order to share fact base for cross-use of the side streams.
- Develop the database to implement key elements such as:
    - Research done on side streams, both successful and failures
    - Possible markets
    - Ongoing work
    - Matchmaking
- Facilitate workshops for open innovation.
- The regulations are not fit to the circular economy. Examples have been given for use as soil amendment, liming in agriculture, for landfill, disposal coverage, for use as pozzolanic material in cement and for aggregates in road construction. Thus, to enhance circular economy, there is a need to discuss these issues with the relevant authorities.

## 4. Recommendations for future use of collected data

### 4.1 Status of the database

The database has been developed through insight from the collected excel sheets (Phase1). Based on the information given in the sheets and knowledge from the experts, the database has been designed to a more standard data format. The positive effect of standardization of the data is better analyses and comparison of information.

The database step by step:

- Build and model the data base structure
- Import of data from excel sheets into the database

- Build reports and analysis in Power BI
- Security and user access to the database and reports

In addition to the database the project has designed and developed webforms for better quality and reporting of data. The webform will replace reporting by excel.

Webform step by step:

- Design based on excel sheet and database structure.
- Development of webform and user testing
- Sending webform to the companies with the purpose of
  - Quality assurance of the reported data (form prefilled with reported data)
  - Consent to sharing data (different levels for sharing)
- Design and develop an administrator user interface for managing companies, users, and dispatch of forms.

The figure bellow illustrates the principles of sharing data. Each participating company can decide to share all data public or limit the access to only experts and participating parties with an NDA agreement. In both cases the company can choose to hide information in the chemical analysis on a component level for the public.

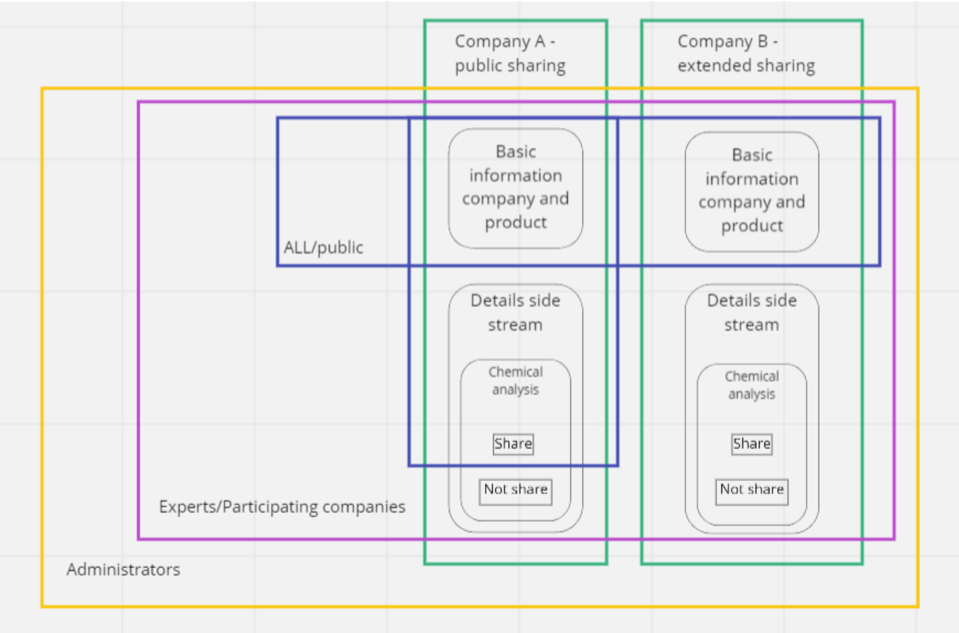


*Figure 3. The principles of sharing data.*

Future use of the database could be to exchange data between external systems to include more information to be used for better analyses and building competence. In addition, the database could be used to collect data from other industries and sectors. By sending the webform and collect data over time we can analyze historical data and see trends and improvements over time.

## 4.2 Mapping of interest for the database (see full report in Appendix 9)

The steering committee decided the project needed input from all parties in the process of giving recommendation for the future management, usage and development of the established database. To conduct this mapping and analysis the project chose the consultant firm AS Boldt, who has broad knowledge of the process industry. Their study was conducted April-May and final report delivered May21. Their findings are summarized in the following:

BOLDT has interviewed 26 individuals (informants) involved in the development of the Norwegian process industry's circular economy database for by-products and waste streams (the database). The informants are representatives from process industry companies (core companies), technology companies, industry clusters, research institutes and industry organizations. The interviews sought to explore three main topics: 1) purpose and user needs, and suggestions for future development, 2) ownership and management and 3) mapping of other similar databases and initiatives.

### *Purpose and use*

There is broad agreement that the purpose of the circular economy database should be to connect companies, research institutes and other actors who want to cooperate to develop circular economy projects, including buying and selling by-products and innovation projects. To act as a match-making platform, core companies should supply a minimum amount of data that can be subject to public access. Core companies who supply data to the database, industry clusters and some other actors can be given access to the full database by issuing login-information and / or subject to signing a non-disclosure agreement. Other companies can be issued login information subject to agreement with member companies. An annual update of the data should suffice to take into account changes in material flows, and to record successful (and failed) innovation projects or new partnerships that have been established.

### *Future developments*

The informants suggest a number of interesting developments to the database including:

- Showing the available by-products and side-streams on a map.
- Allowing access and linking the database to other, similar databases in other sectors or other countries through a digital interface – an API.
- Linking the database to the environmental authority's (Miljødirektoratet) data collection activities to reduce the workload for the companies and lower the threshold for participation in the database.
- Including a reference list to the relevant regulations for handling of each side stream.
- Including materials and wastes that are already on landfill in the database and thereby possibly finding ways to utilize these materials and free up capacity in landfills.

### *Ownership and management*

There is broad agreement that the database should be owned collectively by the core companies, possibly also with the relevant industry clusters. The database should be managed by a neutral, non-commercial actor such as e.g. Norsk Industri or an industry cluster, governed by a board comprised of the core companies. Responsibility for developing the database further can be given to a steering committee comprised of core companies, research institutes, technology companies and other interested stakeholders, possibly also including the environmental authorities.

*Similar initiatives*

A number of similar initiatives exist in both Norway and other countries, though most of them have yet to be properly operationalized. Since most initiatives appear to be in a nascent stage, we recommend arranging a seminar or establishing dialogue to share best practices and learnings and explore the possibilities for links and standardisation. However, the goal of this dialogue should not be to steer all initiatives towards making one "mega-database" that covers "everything", but rather to facilitate the continued organic development of different circular economy initiatives that can be linked together through a digital interface at a later stage.

## 4.3 Recommendations – how to proceed

The steering committee has had a brief discussion of the report, and the representatives are eager to move forward in a partnership to establish a robust organisation for managing, using and developing the infrastructure for sharing data according to the findings and recommendations given by the informants in the BOLDT report. There are both judiciary and financial issues to discuss, and the parties hope there will be interest from the government side to finance this further work.