SINTEF

«Grønne, bærekraftige sommerjobber»

By-product valorisation in Helgeland

Skrevet av
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Executive Summary

This business case explores the possibilities in creating a by-product reutilisation enterprise directed at the Helgeland industry.

A by-product reutilisation enterprise ("NewCo") will provide by-product valorisation competencies and logistics, allowing industrial actors to seamlessly dispose and potentially reuse their by-products. The processed raw materials can be returned to the industrial actors or sold to a third party, and NewCo will be responsible for disposing the fraction of the by-products that cannot be used by sending them to landfills.

The concept presented includes a roadmap and timeline, identifying specific business opportunities that can be seized by NewCo. These include:

1. EAF dust valorisation through zinc extraction (from steel production)
2. Manganese sludge valorisation through zinc extraction and manganese unit reutilisation (from manganese alloy production)
3. Filter dust valorisation through carbon and iron extraction (from aluminium production)

To develop a by-product reutilisation enterprise, we recommend establishing a close cooperation with Miljøteknikk Terrateam and SINTEF Molab, to gain access to their relevant processing, deposit and characterisation capabilities.

A preliminary technology description with a financial analysis and cost estimate is included. Several public funding schemes are available for supporting relevant research and development (R&D) activities, and infrastructure investments. These are described in this business case.

Mission Statement and Description of Business

Mission Statement

To create and provide long term profitable circular solutions for a green and sustainable industry.

Case Objective

To explore the creation of a by-product reutilisation enterprise directed towards the Helgeland industry, and how this can be achieved, with the aim to increase the degree of material circulation and closing of material loops. The goal is to identify and close material loops that have potential for higher utilisation rates.

Business Concept

A by-product reutilisation enterprise ("NewCo") will provide by-product valorisation competencies and logistics, allowing industrial actors to seamlessly dispose of and potentially reuse their by-products. The processed raw materials can be returned to the industrial actors or sold to a third part, and NewCo will be responsible for disposing the fraction of the by-products that cannot be used by sending them to landfills with appropriate treatment for safe long-term storage.

By starting a business for by-product reutilisation, NewCo's value proposition will be:

1. Providing a complete disposal solution for their customers;
2. Closing material loops and assuring a more sustainable product cycle, in line with circular economy principles.
3. Increasing the total raw material efficiency.

In starting a business for by-product reutilisation, NewCo can gain by:

1. Capturing value by processing materials that are currently being shipped abroad
2. Creating value by processing materials that are currently being deposited in landfills
3. Developing capabilities that will ensure a competitive advantage in a future where there is greater demand for, and profit in, by-product valorisation. This includes an overview of existing by-products, material possibilities, and industry potential and needs.

The concept presented includes a roadmap and timeline, identifying specific business opportunities that can be seized by NewCo.

Commercial by-product valorisation vs By-product valorisation test centre

In a previous study (Eidem, 2017) a pilot test-center, "ByTeC", was designed with the purpose of offering test/pilot facilities and accompanying competences from process- and mineral industries. However, the economic framework through the Norsk Katapult[1] funding scheme (ref.) made the ownership- and operational structure difficult to defend commercially.

[1] https://norskkatapult.no/fakta-om-norsk-katapult/

The set-up of NewCo is different, as it focuses on commercial possibilities for by-product valorisation in the Helgeland/Nordland region, offering circular solutions for the industry instead of offering a test or pilot centre. However, by initiating commercial activities based on by-product valorisation and reutilisation, this may effectively develop market needs for a by-product valorisation pilot centre such as ByTeC, thereby increasing the viability of such a centre in the future.

The Problem and the Opportunity

By-product reutilisation: The opportunity at large

We have been witnessing a cultural shift over the last decades, in which there has been an increased focus on environmental issues, sustainability and “green solutions”. As this shift moves through society, it has brought awareness towards the linear economy model of production and its dependence on consumption and disposal. As a reaction to this, emergence of circular economy ideals, models, research, and initiatives have appeared[2]. This is part of a larger global trend of sustainability, in which Europe is at the forefront.

Public perception about climate change, habitat destruction, corporate responsibility and resource depletion has created a sense of urgency about environmental issues, which also can be felt in companies, even though their primary focus is arguably always set on economic profit. There are several reasons for such changes of corporate perspective. As tempting as it may be to ascribe it to philanthropy or altruism, the common theme in corporate push towards sustainable solutions is that: *focus on, and achievement of, sustainable solutions may provide the firm with competitive advantage, today and in the future.*

This may happen through several means:

- Sustainable practice involves leaner practice, with higher raw material utilisation yield. This will lead to a competitive advantage when depletion will lead to future increases in raw material prices, production and transport costs.
- Sustainable practice will set the standards of best practice, and demonstration of sustainability will ensure the firm earns practice permits from the government.
- Research and development towards sustainable practice drives innovation and will position the firm towards earning government and community grants earmarked for sustainable solutions.
- Stricter taxes and fees as incentives for increased by-product utilisation will give material efficient companies an economic advantage.

These means of achieving competitive advantage through sustainable solutions rely on the following assumptions and future outlooks:

1. Industries will be subject to increased government scrutiny and focus on developing sustainable and circular solutions, penalising linear models which do not involve material usage optimisation. This is based on two key elements in the European Circular Economy Action Plan; promotion of economic instruments to discourage landfilling and a binding landfill target to reduce landfill to a maximum of 10% of all waste by 2030. With this focus, stricter taxes and fees as incentives for increased by-product utilisation will be expected in the future. This, in turn, depends on a sustained and growing focus on sustainability in the media, academia and society at large.
2. Industries will have increasing incentives to operate locally, instead of (or in addition to) the global manufacturing and procurement trends that have reigned during the last few decades. Reasons for this may be increased government scrutiny on transportation and shipping as a source of climate issues; but increased uncertainty

[2] https://trends.google.com/trends/explore?date=all&q=circular%20economy

derived from trade protectionism and globalisation trends may also be a driver for local operations.

When it comes to understanding the potential in capturing value from their operations, industries are understandably myopic. They focus on their core competence, and do not have an overview about the possibilities that lie in their by-products – after all, they are just the *by-products*. But in tomorrow's reality, where sustainability, circularity and local action are key drivers for competitive advantage, there are great rewards to be reaped by a better utilisation of raw materials – social, environmental, and not least economical. To be able to obtain these rewards depends on intimate industry and by-product knowledge, and further on industry trust, contact and cooperation. Herein lies the value of an actor that can assess, describe and characterise by-product streams and close by-product material loops. Such an actor will drive industry innovation and cooperation and provide the industry with a competitive advantage. It will also secure value creation and retention on a regional and national level.

By-product reutilisation: The opportunity at hand

In table 1, some examples of by-products in Helgeland that can be reutilised through a by-product valorisation centre are listed.

Table 1: Examples of existing by-products.

Company	By-product	Volume	Potential products
Celsa	EAF dust	8 ktonnes per year	Zn, Fe, Pb
Celsa	Ladle slag	17-18 ktonnes per year	Metals and oxides for mineral and process industry
Celsa	Black slag	60 ktonnes per year	
Ferroglobe	SiMn-slag		
Ferroglobe	Sludge	4 ktonnes per year	MnO, Zn
Alcoa	SPL	4.2 ktonnes per year (25-30 kt/yr in Norway)	Carbon Raw material for refractory products and construction
Alcoa	Dross		Al, Al2O3
Alcoa	Filter dust	1.3 ktonnes per year per year	Iron and carbon
Alcoa	Anode mass		
Elkem	Radiclone dust		
Elkem	Quartz fines		Agglomerated products
Rana Gruber	Surplus material/sand	3 000 ktonnes per year	Fe-oxide, other oxides

The Helgeland Region

Helgeland has an important industrial tradition and presence, particularly the processing industry in Mo i Rana and Mosjøen. Helgeland's vast access to hydroelectric power makes its processing industry one of the more environmentally sustainable among their European peers. The Helgeland processing industry aims for continuous improvement of their environmental footprint and product usage optimisation, to ensure world-class sustainability as a competitive advantage in the future.

The Actors

MIP

Mo Industrial Park AS (MIP) is the largest industrial park in Northern Norway. Sustainability is an express part of MIPs vision and strategic position, aiming "to become a world-class industrial park that creates value through a focus on environmentally friendly and energy-efficient services and solutions"[3]. The industry at MIP is noted as "pioneering" in the fields of

[3] http://www.mip.no/en/mip-sustainability/

by-product reutilisation (see Figure 1) in the Norwegian Parliamentary White Paper on waste policy and Circular Economy[4].

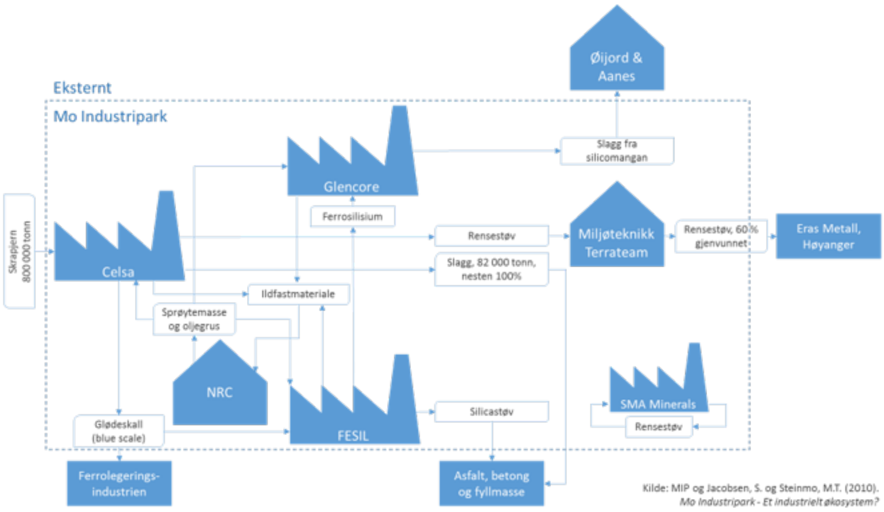

Figure 1: Existing by-product valorisation at Mo Industripark (source: MIP, Jacobsen, S. and Steinmo, M.T. (2010))

SINTEF Molab

SINTEF Molab is one of Norway's largest industrial laboratory companies, headquartered at MIP. Activities include chemical analysis (including waste characterisation), materials testing, environmental measurements and -environmental consulting. SINTEF Molab has an important role and well-developed contacts within the MIP/Helgeland industry ecosystem.

Miljøteknikk Terrateam

Miljøteknikk Terrateam AS is located in Mo Industrial Park, and is a subsidiary of the company Øijord & Aanes AS. Miljøteknikk Terrateam's main activity involves receiving hazardous waste, mainly from industry, analysing the waste, treatment of it, and binding it using cement. The processed masses are then landfilled in the old mines in Mofjellet Berghaller AS. Other activities performed by Miljøteknikk Terrateam include industrial cleaning, lab analysis, and industry by-product agglomeration and pelletisation, primarily dust and sludge.

Miljøteknikk Terrateam takes part in the valorisation process of Celsa Armeringsstål's EAF dust. They are responsible for collecting the dust at Celsa's plant, and pelletisation at Miljøteknikk Terrateam's premises. Miljøteknikk Terrateam then cache it in the mountain awaiting transport. After amassing a sufficient volume of pellets, these are then transported to the Mo i Rana harbour and shipped to Germany for further processing.

Transitioning towards a circular economy and "zero-waste" future, industry needs for Miljøteknikk Terrateam's landfilling services may decrease. Landfilling capabilities are also finite, although they have enough available space for decades at today's landfilling rate. By

[4] Meld. St. 45 (2016-2017), "Avfall som ressurs – avfallspolitikk og sirkulærøkonomi", Klima- og miljødepartementet

expanding their current activities, Miljøteknikk Terrateam could create and capture value in a circularly-oriented future.

Alcoa Mosjøen

Alcoa Mosjøen is a part of the multinational corporation Alcoa and produces high-quality aluminium foundry alloys and billets in the town of Mosjøen, 90km from Mo i Rana. Alcoa Mosjøen has a capacity of 188 000 tonnes of primary aluminium a year. The company has a vertically-integrated anode factory for aluminium production purposes. Alcoa Mosjøens production runs on hydroelectric power. Alcoa Mosjøen has recently entered a long-term contract to access wind power from the Kvitfjell/Raudfjell windmill parks in Troms[5].

The multinational Alcoa has stated goals of reducing the greenhouse gas footprint from their smelting operations, and they are currently working on optimizing the portfolio of placement opportunities for by-product materials with a 2020 deadline. They are also in the process of defining specific objectives to be achieved by 2025 and 2030 [6].

Celsa Armeringsstål

Celsa Armeringsstål is part of the multinational Celsa Group, a group of European steel companies headquartered in Spain. Celsa Armeringsstål specialises in reinforcement and rebar and is the leading producer of steel reinforcing products in the Nordic area, where Celsa operates under the group Celsa Nordic.

The facilities in Mo i Rana were acquired by the Celsa group in 2007. The production is based on scrap, and each year they melt about 670 000 tonnes of scrap metal into 615 000 tonnes of steel product, effectively making Celsa Armeringsstål Norway's largest recycler, measured in tonnage. This, in combination with the use of hydroelectric power as their primary energy resource gives Celsa Armeringsstål a high environmental profile[7].

Celsa Group has expressed that they want their plants to reuse the maximum amount of waste generated during production processes, thereby minimizing the material consumption and reducing the amount of waste that must be handled externally[8].

Elkem Rana

Elkem Rana is part of Elkem Silicon Materials and produces ferrosilicon in two furnaces in their facilities on at MIP. The yearly production capacity is about 90 000 tonnes ferrosilicon that is mainly exported and used in steel production, and 23 000 tonnes of the by-product microsilica which is sold to the cement industry. The bulk of the production is made up of special products including granulated and refined qualities.

Elkem Rana is based on renewable hydropower and the energy recovery represents approximately 30% of the electricity input[9]. Sustainability is central for the multinational

[5] https://www.alcoa.com/norway/no/news/releases.asp?id=2017/10/norway&year=y2017
[6] http://www.alcoa.com/sustainability/en/environment-health-safety.asp
[7] http://www.celsaarmeringsstaal.com/Celsa.mvc/Presentacion
[8] http://www.gcelsa.com/secciones/corporate/environment.aspx
[9] https://www.elkem.com/no/contact/elkem-rana/

Elkem, and they have continuous efforts to maximise their positive impact on the environment and minimise any negative impact. Because of this, Elkem is always looking for new and innovative ways to reduce waste and emissions and get more out of their raw materials[10].

Ferroglobe Mangan Norge

Ferroglobe Mangan Norge AS is part of the Spanish Grupo FerroAtlántica S.A., a subsidiary of Ferroglobe PLC with headquarters in London which is one of the world's largest producers of ferro- and silicomanganese[11]. In late 2017, Ferroglobe PLC bought all the shares in Glencore Manganese's smelter in Mo i Rana where they produce manganese alloys in two furnaces with a total capacity of 120.000 tonnes per year.

Ferroglobe PLC promotes a responsible environmental policy which is illuminated by numerous investments in environmental measures, representing 10% of their total investments recent years[12].

Market Assessment

NewCo will be established in a strategically advantageous position in Helgeland, Northern Norway, located in the regional industrial hub of Mo i Rana. This location gives the company easy access to important industrial actors Celsa, Elkem, Alcoa and Ferroglobe; key partners SINTEF Molab and Miljøteknikk Terrateam. Glomfjord Industrial Park and Elkem Salten further north are also potential partners (The area ranging from Vefsn in the south to Salten in the north will be named "central Nordland" when relevant to this case).

Significant industrial actors housed at MIP include Celsa Armeringsstål, Elkem Rana and Ferroglobe, with Alcoa Mosjøen a short drive (90 km) away. All of these companies express commitment to sustainability, environment and/or resource and energy efficiency as part of their stated corporate strategy. Being subsidiaries of large multinationals, these companies' focus on sustainability mirror a global industry trend[13]. The Norwegian government report "Grønn Konkurransekraft"[14] and several industry roadmaps[15,16] highlight the need for greater resource utilisation levels and the need for industry innovation, in order to meet future zero-emission goals.

Achievement of greater resource efficiency is a stated goal in Norwegian state, EU and UN documents, plans and proposals. Initiatives like the European Circular Economy Action Plan mark a ramp-up in efforts to transform the European economy into a circular-oriented one. Some key elements in the Action Plan is:

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[10] https://www.elkem.com/sustainability/

[11] http://investor.ferroglobe.com/news-releases/news-release-details/ferroglobe-completes-acquisition-glencores-european-manganese

[12] http://www.ferroatlantica.es/about-ferroglobe/quality-environment-safety/?lang=en

[13] https://www.theguardian.com/innovative-sustainability/2017/oct/31/charting-the-course-of-sustainability-in-business-from-the-1960s-to-today

[14] Regjeringens ekspertutvalg for grønn konkurransekraft, «Grønn konkurransekraft», oktober 2017

[15] https://www.norskindustri.no/siteassets/dokumenter/rapporter-og-brosjyrer/veikart-for-prosessindustrien_web.pdf

[16] https://www.norskbergindustri.no/siteassets/publikasjoner/veikart.pdf

1. A binding landfill target to reduce landfill to a maximum of 10% of all waste by 2030.
2. The promotion of economic instruments to discourage landfilling.
3. Concrete measures to promote re-use and stimulate industrial symbiosis, turning industrial by-products into raw materials[17].

Among the instruments to obtain the goals in the Action Plan is Horizon 2020 (see Appendix A8) and promotion of repairs, durability and recycling (see Appendix A9 for a proposed instrument "Gjenova", under this category).

Government-mandated zero-landfill goals from state hold make it a priority to develop ways to extract both raw material and contaminated matter from industrial by-products in order to achieve safe and effective disposal of industrial waste, keep resources in circulation, and preserve the limited available areas for future landfilling.

Industry, political and societal trends all point towards a greater focus on circular economy and material reutilisation, and there will subsequently be a greater need for actors that drive innovation and provide solutions for these emergent needs and problems.

Market Segmentation

Operating a by-product valorisation centre will involve the transportation of significant quantities of by-product masses. This will impact the feasibility and profitability of projects on a case-to-case basis, and location is therefore a segmentation base. NewCo will focus on the MIP/Helgeland industry ecosystem. NewCo's key partner Miljøteknikk Terrateam has developed relations with and insight into the decision-making unit in the aforementioned industries and industry clusters in central Nordland.

For by-product valorisation purposes the most evident sources are industrial by-products from the metal producing and processing industry, such as filter dust. NewCo should focus on closing material loops in the metal producing and processing industry.

[17] http://ec.europa.eu/environment/circular-economy/index_en.htm

Business goals and Strategy

Business Model

NewCo's aim is to offer a complete sustainable disposal solution for the customers. The company will assure their customers that their by-products are characterised, processed and recycled in a sustainable and environmentally friendly manner. The long-term goal is to offer recycling and material handling for a wide range of industrial by-products. Offering a complete disposal solution, NewCo will:

1. Recover valuable materials from industrial by-products;
2. Sell upgraded secondary raw materials from extraction processes that cannot be reused locally;
3. Safely deposit hazardous materials (that cannot be recovered) in mountain landfills.

Cooperation with Miljøteknikk Terrateam

In order to offer a complete sustainable disposal solution, we recommend that NewCo establish a close working relationship with Miljøteknikk Terrateam. The reasons for close cooperation are several:

1. Miljøteknikk Terrateam has well-established presence in the MIP/Helgeland industry ecosystem, with ongoing relationships and presence in existing by-product disposal chains.
2. Miljøteknikk Terrateam has expressed interest in expanding their operations to include a bigger focus on by-product reutilisation and closing product loops.
3. By engaging local competencies with focus on by-product reutilisation, the Helgeland industry can achieve environmental benefits and greener production without stepping out of their core competencies.
4. A "zero-waste" future does not necessarily mean that nothing is deposited in landfills. Hazardous materials do still have to be handled and brought out of the product cycles. Miljøteknikk Terrateam's capabilities in handling and landfilling hazardous materials are crucial to offer a complete sustainable disposal solution. Furthermore, it is not necessarily given that the competitors can offer such a solution, this way providing NewCo with a competitive advantage.

Cooperation with SINTEF Molab

SINTEF Molab is well-integrated within the MIP/Helgeland industry ecosystem and has key competences within waste/material characterisation and testing that are important for development of sustainable disposal solutions.

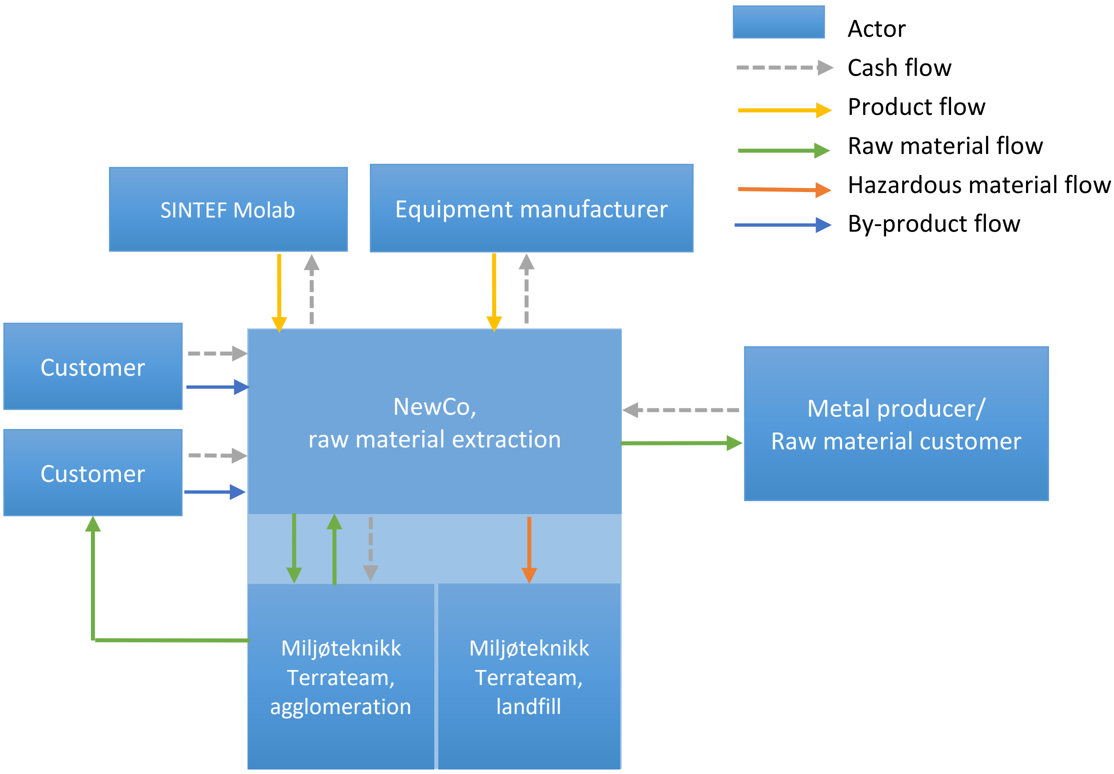

Figure 2: Business model for NewCo.

Business Development Strategy

A first step will be to establish a close cooperation with Miljøteknikk Terrateam. This is important, in order to access Miljøteknikk Terrateam's processing and deposit capabilities, and existing roles in local by-product disposal chains. For Miljøteknikk Terrateam this cooperation is crucial to expand their core competences and operations to ensure their competitiveness in a zero-waste future.

The exact nature of this relationship and company organization is still to be determined. NewCo will initially focus on recycling three selected by-products from the local industry in Helgeland: EAF-dust from Celsa, manganese sludge from Ferroglobe and filter dust from Alcoa. With this as a basis, NewCo in cooperation with Miljøteknikk Terrateam will seek to expand their network of customers in Nordland by developing capabilities in handling and recycling their by-products as well as offering extracted valuable materials on the market.

Table 2: Business development goals for expansion. See visualised timeline in Appendix A10.

Schedule	Task
January 2019	Initiate pre-project R&D on EAF dust from Celsa
January 2019	Initiate pre-project R&D on manganese sludge from Ferroglobe
January 2019	Initiate pre-project R&D on filter dust from Alcoa
January 2020	Initiate primary R&D project on EAF dust
August 2020	Initiate primary R&D project on manganese sludge
August 2020	Initiate primary R&D project on filter dust
January 2022	Extraction of zinc oxides from EAF dust starts
August 2022	Extraction of zinc oxides and treatment of manganese sludge starts
January 2023	Extraction of valuable components and/or treatment of filter dust starts

Establishing valorisation projects of these three by-products, as well as an ongoing project with Elkem regarding agglomeration of by-products, NewCo in cooperation with Miljøteknikk Terrateam should have a solid starting point for becoming a centre for by-product valorisation. During a preliminary literature study, no such centers for complete solutions were found; only actors that recycle their own by-products like Tapojärvi, or actors such as Befesa that focus on single by-products like steel dust and aluminium slags (see Appendix A2).

Research and Development

It is a natural part of the business development to become able to perform research and development alongside the requisite testing in-house, but the capability for this will have to be built up in equipment and competencies over time as aiming for this from the get-go will be problematic both in capital and availability of skilled staff.

The intent for our proposed business development process is that initial R&D is performed entirely by outside contractors with the necessary expertise and equipment such as NTNU Oppredningslaboratoriet, SINTEF, ReSiTec, Outotec or Metso.

We estimate an R&D cost of 2.0 MNOK for the EAF dust project, to be outsourced entirely (See "Financials" chapter).

Several public funding schemes are available for research of this nature, such as "Miljøteknologiordningen". See Appendix A8 for further detail and alternatives.

Business Expansion Strategy and Timeline

1. Zinc oxide extraction from EAF Dust

Electric Arc Furnace (EAF) dust is an inevitable waste product of EAF steel production such as that of Celsa Armeringsstål AS and is frequently treated and landfilled as hazardous waste. It is possible to recover an amount of valuable metals from the EAF dust, and the current arrangement is that Celsa sells its EAF dust to Befesa in Germany where it is treated in a pyrometallurgical process (WAELZ) to extract the zinc into quite pure zinc oxide form (Befesa, 2018b) before selling it to a zinc metal producer who processes it into metallic zinc.

Currently, Miljøteknikk Terrateam has an intermediate processing role between the EAF dust origin at Celsa, and the end customer Befesa, where Miljøteknikk Terrateam prepares EAF dust for shipping to Germany by agglomerating (pelletizing) the EAF dust for transportation purposes.

The potential here is to end the current practice of preparing the EAF dust for shipping on behalf of Celsa, and instead separate and sell the primary valuable zinc oxides from Mo i Rana, creating and capturing value locally and saving the environment for a significant amount of emissions from transport and processing. It is likely that other valuable constituents such as magnetite can be extracted as a result of this process.

Celsa Armeringsstål generates EAF dust in the order of 8,000 tonnes/year[18] and has the necessary mandate and opportunity to negotiate locally about the disposition of their EAF dust, meaning access to the potential resource is available. The EAF dust contains approximately 35-40 % zinc in the form of zinc oxides, from which an estimated 23 MNOK revenue can be gained yearly[19](se Appendix A12).

The recovery of zinc oxides from the EAF dust can be performed locally with very large environmental savings compared to todays' practice. A preliminary calculation suggests CO_2-equivalent emissions would be reduced by 97%[20] by performing zinc oxide separation locally (see Figure 3 and 4). This is a vast reduction, primarily due to the highly energy-inefficient (Oustadakis et al., 2010, Suetens et al., 2014) process used in Germany and the very large difference in CO_2-equivalents in Norwegian and German electricity mix (RE-DISS, 2015, Moro and Lonza, 2013, NVE, 2016). See Appendix A11 for further detail on the environmental accounting.

[18] This amount would increase alongside the steel production should that increase
[19] Our calculated estimates range from 17 MNOK to 33.5 MNOK based on zinc metal price (2000-3000USD/tonne), zinc oxide recovery from EAF (75-85%), zinc content in EAF (34-40%), and assuming
[20] From 2.35 to 0.06 tonne CO_2 per tonne EAF dust

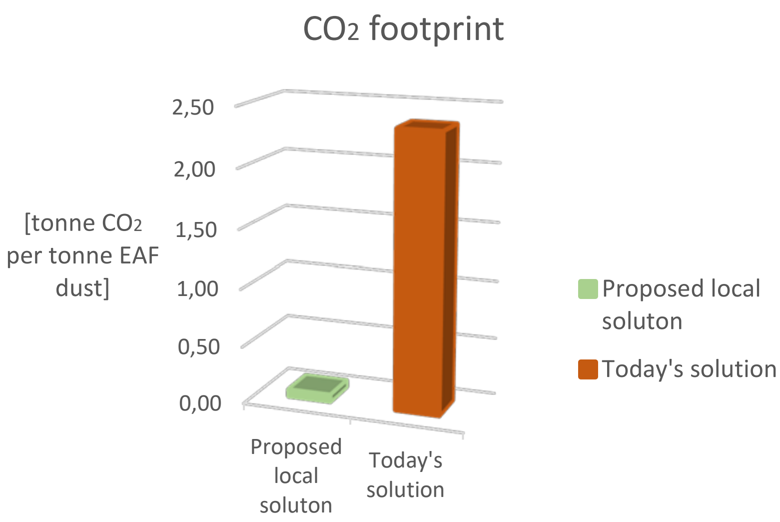

Figure 3: Comparison of total estimated CO_2 emissions from today's solution versus the proposed local solution (from stored EAF dust to processed zinc metal) (see Appendix A11).

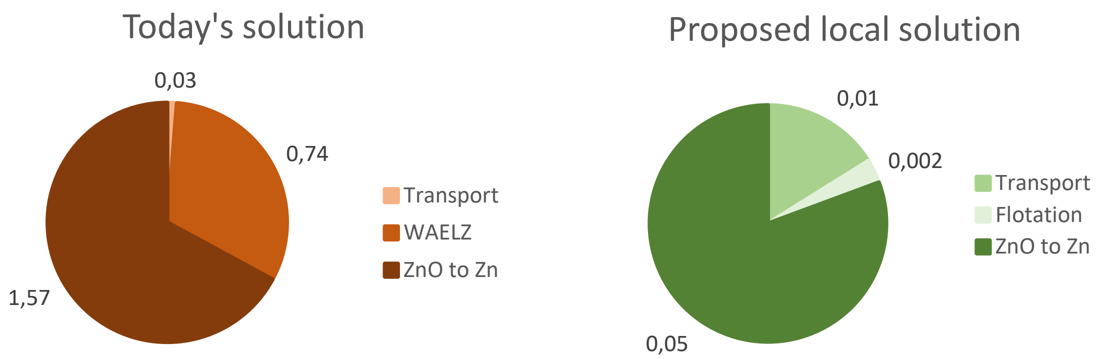

Figure 4: comparison of CO_2 emitting processes in both today's and the proposed local solution. For the full list of assumptions and sources used in the estimation, see Appendix A11. Appendix A11 also contains further division of processes and transportation.

Data from a WAELZ process in Spain (Befesa Zink Aser, 2016) is used to compare the total energy consumption of a WAELZ process against an estimate of the energy consumption of the proposed local solution. These are the two processes for extracting ZnO from EAF dust (see Figure 5).

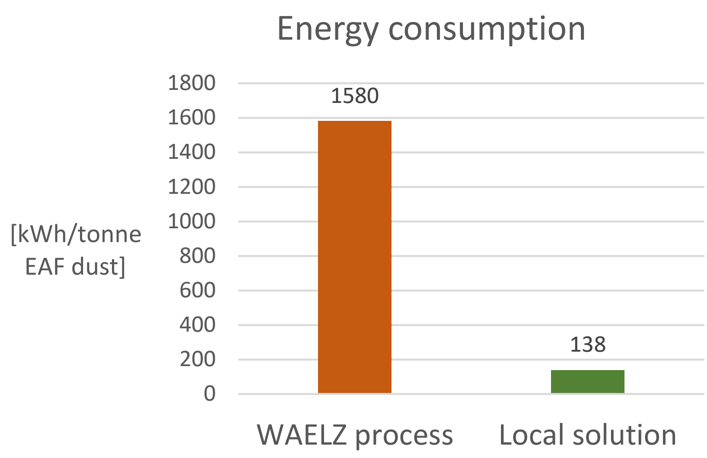

Figure 5: Energy consumption comparison between the different ZnO extraction processes.

2. Zinc oxide extraction and reuse of manganese sludge

Ferroglobe Mangan Norge AS produces ferromanganese alloys, and in a similar manner to EAF dust an amount of waste material is inevitable. The air filtration system is rinsed with water, generating 4,000 tonnes/year of sludge rich in manganese. Lacking a better alternative, the sludge is handled by Miljøteknikk Terrateam where it is currently landfilled.

Ferroglobe has previously attempted to dry, pelletise and re-use the sludge in their FeMn-alloy production, but the zinc content has proven to be problematic sludge for re-usage, due to the comparatively low boiling point of zinc and resulting volatility in the furnace. If the zinc was to be removed, the sludge would be re-usable as a raw material for Ferroglobe, valued on par with low-grade manganese ore.

A process wherein the zinc oxide content is removed from the sludge before the remnant is dried, pelletised and returned to Ferroglobe would then be profitable to all concerned parties. The zinc oxide can be sold to a zinc producer. Miljøteknikk earns money on the service of zinc removal and selling zinc oxide, while Ferroglobe will gain access to raw material valued at 3.7 MNOK.

As the sludge is currently landfilled by Miljøteknikk Terrateam, the sludge is already available as a resource. Ferroglobe would have no interest in restricting the zinc oxide separation.

3. Filter dust from aluminium plant

Alcoa Mosjøen is preparing for changes in waste management during the next two years. Whereas they have been using their own landfill premises, they are presently increasing their efforts in recycling their waste materials.

Filter dust is a by-product of anode reutilisation at Alcoa Mosjøen. Worn out anodes are subject to a cleaning process, which involves four work stations. Each station has a filter for exhaust gas. Some of the resulting filter dusts include iron and copper, and some include carbon and cryolite. Approximately 1300 metric tonnes of filter dusts are produced annually.

The filter dusts are currently dealt with through landfilling, but Alcoa Mosjøen is interested in finding alternative solutions, such as by-product valorisation and reutilisation. The filter dusts' most valuable components for extraction are primarily iron and carbon. The value and reutilisation possibilities depend on processing capabilities.

We propose a filter dust valorisation project as part of an expansion of NewCo's by-product valorisation activities.

The case of EAF dust management

Problem

When Norsk Jernverk AS started producing steel in Mo i Rana, the town was soon dubbed "the red town" due to the reddish-coloured dust that left the plant through the pipes and fell down in the surrounding areas. Today, regulations make sure that the dust is captured before exhaust. Once this dust is collected, it needs to be disposed. In the past the dust was landfilled, but today it is processed by Miljøteknikk Terrateam and sold to Befesa in Germany. This arrangement benefits Celsa as they don't have to support expenses relating to landfilling of the dust, but there is room for improvement as the current revenues from EAFD sales are about the same as the cost of transporting them to Befesa. As of today, the majority of the value created by EAF dust processing are lost to Germany and Befesa, and the transportation and extraction process have significant environmental impact.

Solution Offering

NewCo will be responsible for all handling and processing of the EAF dust from Celsa, in cooperation with Miljøteknikk Terrateam. EAF dust at Celsas plant will be collected in the same manner as it is today, but instead of pelletizing and shipping the EAF dust to Germany, NewCo will extract the zinc oxide and sell this to a zinc producer. Any usable remains of the EAF dust will preferably be sold to a local actor that can make use of it, and the parts that cannot be used will be landfilled. This way the value created from EAF dust processing is kept locally. An estimate shows that the environmental impact by transportation and processing is decreased from 2.35 to 0.06 tonnes CO_2-equivalents per tonne EAF dust by switching to this solution (see appendix A11).

Preliminary treatment process

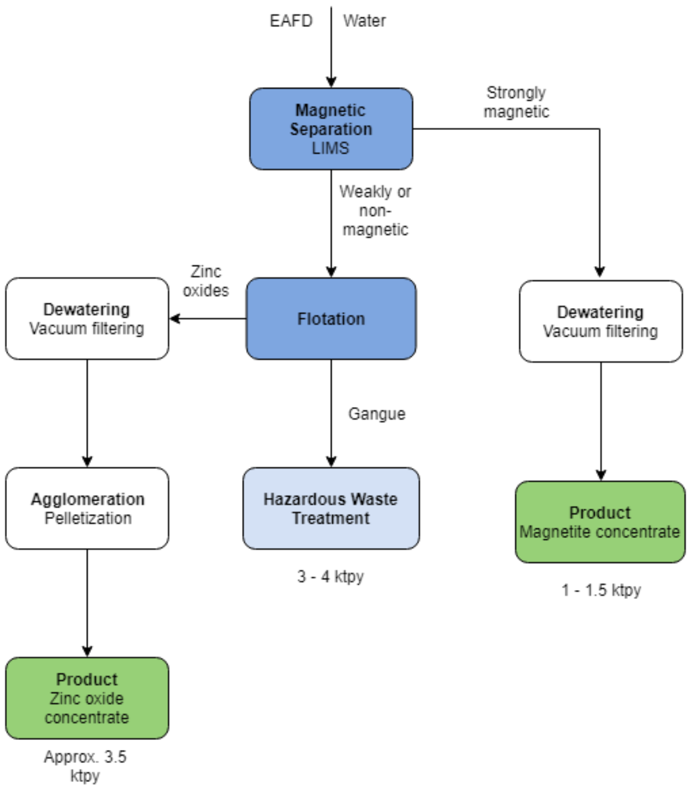

Figure 6: One approach to EAFD processing

A preliminary process circuit and flow sheet has been outlined above. A fair amount of R&D remains before it is possible to make final choices on how best to process the EAF dust, but this provides an example of how the process might look given a number of assumptions.

Further detail on separation technologies in general and some more details on the flowsheet above can be found in Appendix A1, as well as on the equipment and capital investments necessary in Appendix A5.

Target Market and Customer Analysis

The customer – Celsa Armeringsstål

Favourable Environmental Product Declarations (EPD) is important for the construction industry. These declarations are based on the product life cycle analysis. Celsa Armeringsstål showcases some of the most favourable EPDs in the European steel reinforcement industry. When purchasing the facilities in Mo i Rana, Celsa Armeringsstål "inherited" substantial EAF dust deposits from the previous owners. These deposits were landfilled according to environmental regulations and practice during the time; however, not all of these landfills ascribe to present standards and may present a future liability. If a cost-effective by-product valorisation solution is presented, opening these landfills for EAF dust extraction may be considered.

The zinc oxide purchaser – Boliden

As Celsa specialises on ferrous metal recycling, it has no use for the zinc oxide extracted from the EAF dust. To close the material loop it is then necessary to find a partner that can receive the zinc oxide resulting from the zinc extraction process.
Boliden is a metal multinational which owns both mines and smelters and has zinc smelter operations in Norway and Finland. It is therefore a potential zinc oxide purchaser.

In the smelters, Boliden refines mineral concentrates into pure metals. Due to technical expertise and flexible processes, Boliden can extract metals from complex raw materials and produce metals of very high quality[21].

The smelters operated by Boliden which may process the zinc oxide extracted from the EAF dust are:

Boliden Odda

Located in Odda, Western Norway, Boliden Odda's primary raw materials are zinc concentrates for zinc production. Boliden Odda has undergone extensive streamlining work and invested in new process equipment in recent years. Boliden Odda's zinc production in 2016 was 172 ktonnes, and it is a stated goal to reach an annual capacity of 200 ktonnes[22]. Boliden Odda is roughly a 1100km, 17-hour drive from Mo i Rana. This smelter is accessible by ship. In the financials section of this case, Boliden Odda is assumed as zinc purchaser, with the zinc oxide being transported by ship.

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[21] https://www.boliden.com/operations
[22] https://www.boliden.com/operations/smelters/boliden-odda

Boliden Kokkola

Located in Kokkola, on the west-coast of Finland, this is Europe's second biggest zinc producer, with a production of 285 ktonnes in 2017. Thanks to continuous development the smelter is world class in terms of low emissions and energy efficiency[23]. Boliden Kokkola is roughly a 950km, 12-hour drive from Mo i Rana.

Competitive Analysis

Today, the EAF dust from Celsa Armeringsstål is sent to Germany, where the zinc oxide is extracted. The German plant that treats the EAF dust is part of Befesa, a multinational that specialises in recycling hazardous waste from the steel and aluminium industry. They have 11 plants in 6 countries that recycle EAF dust and 7 plants in 3 countries that recycle aluminium salt slags. 43% of Befesa's sales income stems from their steel dust recycling services, resulting in €312m in 2017 from steel dust. In 2017, 83% of their EBIT was from steel dust recycling services, resulting in €120m with an EBIT margin of 36% in steel dust recycling services. They have 45-50% market share in steel dust recycling services in Europe (Befesa, 2018a). Befesa is the main competitor, as they are currently providing the service of recycling zinc.

Assuming that Befesa achieves a 95% recovery rate on the EAF dust it receives from Celsa Armeringsstål (for EAF value estimates, see Appendix A12), we estimate the sales value of that particular zinc retrieval operation to be around €2.8m. This accounts for 0.8% of Befesa's steel dust recycling income, and 0.3% of Befesa's total sales income.

Boliden Rönnskär is a world leader in electronics recycling located in Skelleftehamn in Västerbotten, Sweden (Boliden Group, 2018a). They extract mainly copper, but also gold and silver from electronics waste. A by-product of the copper production is the slag product zinc clinkers, which is a yellowish powder that zinc is extracted from (Boliden Group, 2018b). Boliden can be a competitor, as they may be interested in the EAF dust to extract the zinc.

Zinc Oxide Extraction Financials

An estimate has been made of the likely revenue from the EAF dust, based on a range of variables and assumptions.

The extractable income of EAF dust ranges from a low estimate of $2.1 million USD (17.2 MNOK) per year to a high estimate of $3.6 million USD (34.2 MNOK) per year, with $2.6 million USD (21.6 MNOK) as the middle estimate. See appendix A12 for further details.

[23] https://www.boliden.com/operations/smelters/boliden-kokkola

The case of sludge management

Problem

As Ferroglobe produces manganese ferroalloys, inevitably resulting in exhaust that needs to be cleaned. The gases go through scrubbers where water is used to clear the gases of unwanted elements, and the water is then rinsed of these unwanted elements. The result is a sludge that is sent through pressing filters to remove as much water as possible. The sludge is rich in manganese that would be advantageous to recycle into the furnace, but the zinc and alkali content in the sludge makes it unfavourable to do so. Too high amounts of zinc and alkali in the furnace is a risk, as it increases the chances of bridging of raw materials and blowouts. The sludge therefore needs to be disposed of, and it is presently sent to Miljøteknikk Terrateam to be landfilled.

Solution Offering

NewCo will handle the sludge on behalf of Ferroglobe. Instead of today's practice of landfilling they can treat the sludge and extract the zinc oxide. The sludge can then be returned to Ferroglobe to be recycled into the furnace, and the zinc oxide can be sold to a zinc producer. Any remains that cannot be used will be landfilled. In this way, the values in the sludge are utilised, the amount of manganese ore Ferroglobe uses is decreased and the need for landfilling decreases.

Target Market and Customer Analysis

The customer - Ferroglobe

Ferroglobe Mangan Norge has an existing customer relationship to Miljøteknikk Terrateam today where Miljøteknikk Terrateam receives the sludge from Ferroglobe and puts it into landfills. Ferroglobe would have no interest in restricting the zinc oxide separation.

Ferroglobe also sit in possession of old landfills that they have "inherited" from previous owners of their manufacturing premises. If a cost-effective solution for extracting zinc oxide is established, opening these landfills should be considered.

Value appropriation and offering

Miljøteknikk Terrateam's present-day handling of Ferroglobe's sludge is an indicator of Ferroglobe's willingness-to-pay (WTP) for a solution to this particular by-product, and it also sets Miljøteknikk Terrateam's opportunity cost – it needs to be better off by providing the by-product valorisation solution.

Including zinc oxide extraction in the sludge handling will increase Ferroglobe's willingness to pay by the amount of the value of the manganese-rich sludge which can then be recycled as raw material. On top of this comes the (presently more-or-less) intangible value of a greener production footprint.

$$WTP_{future} = WTP_{present} + Value_{sludge}$$

Present-day costs include processing costs to make the by-products suitable for landfilling and direct landfilling costs.

Future costs will include sludge processing costs.
By extracting zinc oxides from the sludge, this can be resold alongside the zinc oxides extracted from EAF processing. This will offset the processing costs.

In order for this process to be profitable, future net costs need to be lower to the present net costs for Miljøteknikk Terrateam. This can be expressed thusly:

$$Costs_{processing} - Value_{zinc} \leq Costs_{landfilling}$$

The zinc oxide purchaser – Boliden Odda

As a manganese alloy producer, Ferroglobe has no use for the zinc oxide extracted from the sludge. Therefore, Boliden is proposed as a zinc oxide customer, referring to the case of EAF dust management on page 19 for more details.

Competitive Analysis

Eramet Norway has three plants that produces manganese ferroalloys. They are working on finding new ways to use their sludge, to better utilise the materials and to decrease the landfilling. In the project "Waste to Value" that involves several other companies, Eramet has used sludge and dust to make pellets that can be tested in the furnace. They also work on using sludge and dust as input material in briquetting (Eramet Norway, 2017). Eramet can be a competitor to Miljøteknikk Terrateam if they find a way of reuse the manganese in the sludge.

Financials

Assumptions and Comments

Table 3: Assumptions and comments in financial analysis

	Assumption	Comment
Transport price	253 NOK per tonne estimate:	
Shipping price	*125 NOK per tonne*	*Tom Engø, Strand Shipping*
Port charges	*6 NOK per tonne*	*Based on Mo i Rana port pricing*
Load/unload costs	*22 NOK per tonne*	*Pellet load price*
Transport price inside Mo	*50 NOK per tonne*	*Local transport happening during several stages of process*
Storage and Cache	250 NOK per tonne	
Operating expenses	Processing wages under Costs of Goods Sold	
Depreciation	10-year linear depreciation with no salvage value	
R&D	2,0 MNOK R&D cost per project	
R&D Funding	40% of R&D costs	
Construction expenses	30% of Machinery expenses	
Infrastructure expenses	30% of Machinery expenses	
Instrumentation expenses	50% of Machinery expenses	
Facility Building	30% of Machinery expenses	
Magnetite	Sales income of magnetite neglected	Could be valuable, but hard to estimate
Wages	Management: 1x FTE at 1 200 000 NOK Operations: 2x FTE at 750 000 NOK	

Income Statement

Table 4: Income Statement

	2019	2020	2021	2022	2023	2024	2025
Income Operations							
Sales Zn				28 324 500	28 324 500	28 324 500	28 324 500
Sludge Valorisation				3 712 562	3 712 562	3 712 562	3 712 562
R&D Funding	600 000	1 800 000	0	0	0	0	0
Operating Expenses							
Research and Development	1 500 000	4 500 000					
Cost of goods sold	0			21 247 314	21 247 314	21 247 314	21 247 314
General and Administrative	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Depreciation			444 499	444 499	444 499	444 499	444 499
Net Income Before Taxes	**-2 100 000**	**-3 900 000**	**-1 644 499**	**9 145 248**	**9 145 248**	**9 145 248**	**9 145 248**

For cash flow projection, see appendix A7.

Funding

The out-of-pocket capital and expenses for the first year will be 2.1 MNOK.

The public funding scheme "Miljøteknologiordningen" (described in Appendix A8) would appear to be a highly relevant option, and if granted support could be as high as 45%-55% of the investment and R&D along with other possible public funding instruments.

Capital Requirement

An assessment of the required capital for the proposed processing circuit of EAF dust for zinc oxide and magnetite extraction has been made and is estimated at 17.7 million NOK.
The current proposal is preliminary, and there will likely be significant changes regarding process, material and other assumptions. A reiterated proposal delivered after R&D developments is likely to produce different results. These preliminary numbers should be considered a ballpark estimate.

This has been based on scaling to a capacity of 10 tonnes/hour, intended to be run for 7 effective-hours daily for 5 days/week. This operating-time and throughput would be capable of handling around 15,000 tonnes/year. While even this is a greater capacity than strictly necessary to process the available yearly EAFD and any realistic increase in that alone, the intent is to leave the equipment available for parts of the year for alternative use both in processing of other raw material such as the Ferroglobe sludge, and for use in future test programmes on other by-products for potential treatment.

This includes the necessary machinery, building and construction, infrastructure, instrumentation as well as an allotment for unforeseen expenses. It does not include the necessary research and development, nor does it include the capital expenses towards agglomeration capability as Miljøteknikk Terrateam is already planning on adding this for another project.

Under current operating assumptions, the recovery of zinc oxide from the Ferroglobe sludge and processing of the remainder for Ferroglobe re-use will not require any additional equipment. The process will aim to use existing equipment during the time it is expected to not be in use due to the above mentioned over dimensioning of plant capacity. Additional R&D will be necessary to initiate sludge processing, however.

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Appendix

A1 Literature and Technology – Mineral Processing

General findings on EAFD

In general, the zinc oxides found in Electric Arc Furnace dust (EAF/EAFD) are mainly found as zincite (ZnO) and zinc ferrite, also known as franklinite ($ZnFe_2O_4$). In the characterisation performed in (Oustadakis et al., 2010) the franklinite is found in markedly larger grains than the zincite, which may be possible to exploit by classification if the difference is large enough and the divide fairly sharp. In that same study the entire EAFD sample in question was broadly divided into two significant size fractions, very fine at 0.1 – 1 µm, and a coarser of 1 – 100 µm.

(Suetens et al., 2015) found that their EAFD particle size distribution had the submicron fraction (approx. 0.3-0.8 µm) dominated by zincite which made up around 50 % volume of the dust, with the rest being heterogenous particles between 1 and 250 µm. Iron oxide and slag particles made up the 1-40 µm fraction, and the larger fraction generally made up by aggregates of smaller particles.

EAFD commonly includes sizeable amounts of iron oxides, generally as magnetite (Fe_3O_4), hematite (Fe_2O_3) and complex ferrites ($[Me]Fe_2O_4$) (Lottering, 2016).

If, as (Suetens et al., 2015) suggests, the iron oxides are present in significantly larger particles than the zinc oxides, one might consider using low and/or high intensity magnetic separation. Zinc ferrite is rated as about as susceptible as hematite, which is significantly less so than magnetite (Rosenblum and Brownfield, 1999). If the mineralogy and size distribution permits, this can be used to separate iron oxides to a separate product and greatly ease zinc oxide recovery.

Which separation technologies to use and how will always depend on the characteristics of the EAFD, and the requirements of the product recipient or customer. Every individual process must be tailored for the raw material and product at hand (Sandvik et al., 1999).

Separation technologies

Classification

Classification is used in mineral processing to separate particles based on their size (Wills, 2016). In the great majority of applications this is done by screening rather than classification. Screening is performed by conveying a material stream, wet or dry, across a vibrating surface full of openings where the smaller particles are intended to pass through. Screens degrade in capacity and separation efficiency with decreasing particle size, and it is typically considered unfeasible to use screening below 75 – 100 µm for applications beyond lab testing.

Classification itself is based on the settling speed of a particle in a fluid (including air for dry separation) relative to the speed in the fluid itself. With all other factors known, one can specify the updrift of air or water inside a cyclone classifier such that particles below a desired size will float up and exit the cyclone through the overflow, and particles above will sink to the underflow.

One limitation of classifiers is that the settling speed of very fine particles is dominated by but not exclusively influenced by particle size, with density and shape also having some influence. This means the split or *cut-off* on particle size will never be perfect but in practice one can achieve good results nonetheless, with relatively minor amounts of particles near the cut-off size reporting to the wrong outflow.

For separation of wet goods, a hydrocyclone is used. The size of the hydrocyclone correlates with the desired cut-off size and approaching the lower end of feasible wet separation at approximately 10 µm the hydrocyclone needs to be down to 10 mm diameter. It should be no surprise that the throughput capacity of a 10 mm hydrocyclone is very low and would necessitate a large amount running in parallel to be useful.

Air classifiers function on essentially the same principle, but can achieve good separation and acceptable capacity down to a cut-off of 3-5 µm. (Hosokawa, 2013) offers an air classifier capable down to a 3 µm cut-off and listing a throughput of 2.800 kg/hour at the 5 µm cut-off.

Magnetic separation

Magnetic separation is a conceptually very simple separation process where a stream of particles passes through a magnetic field, where magnetic particles will have a far larger force acting on them than non-magnetic particles, which will divert them selectively along a different path where they can be separated from the non-magnetic particles (Wills, 2016).

In practice the situation is not quite so simple, giving a number of challenges and additional opportunities in separation. Different minerals react differently to magnetic fields, with something like magnetite – as the name suggests – responding strongly to magnetic field forces. It is a standard practice to use low intensity magnetic fields to separate out strongly magnetic particles, as their presence in a high intensity separator will cause stoppages or even permanent damage to the equipment[24].

A small particle made of highly susceptible minerals can be as magnetically attracted as a larger particle composed of somewhat susceptible minerals, and unless care is taken in the separator design both may be sorted to the same output.

Leaching

Leaching is a hydrometallurgical process where the material to be processed is immersed in liquid, and desired elements are dissolved by some suitable chemical or circumstance. In a few specific cases water will suffice, but most require conditions like strongly acidic or alkaline pH or a specific leachate.

Acidic leaching of zinc oxides is discussed in (Lottering, 2016), (Hameed et al., 2015) and (Havlik et al., 2012) with all of these based on use of H_2SO_4 in particular. Havlik achieved a maximum zinc recovery of 95 % using 1 M H_2SO_4 at 95 degrees C, but also dissolved a significant amount of iron under those parameters. Lottering achieved 93 % Zn recovery at

[24] Stated in lecture by Prof. Rolf Arne Kleiv, NTNU as part of subject TGB4227 Mineral Production, Basic Course

pH 1.80-1.85 and 50 degrees C. Dissolution of iron may, depending on customer specifications, be an issue.

Alkaline leaching is suggested by (Oustadakis et al., 2010) as a preferable alternative to dissolving zinc ferrite without entraining iron oxides, but notes that it requires relatively concentrated leaching medium. (Dutra et al., 2006) were only able to dissolve the zincite to a somewhat adequate degree, even using 6 M NaOH at 90 degrees C for 4 hours. The overall Zn recovery in their case was 74 %.

Oustadakis states that zincite does not cause any problems to either acidic or alkaline leaching, but that zinc ferrite is considerably refractory against leaching. This is consistent with the results of (Dutra et al., 2006).

Flotation

Froth flotation is a well-established technique for mineral separation in use worldwide, with applications extending well beyond processing of ore from mining into use for waste water treatment and recycling e.g. the removal of ink from paper to be recycled.

The material to be treated is mixed with water to a slurry or pulp and is pumped into the flotation cell. Air bubbles are sent through the pulp from the bottom, and hydrophobic particles will attach to the bubbles and be transported to the top of the cell, where it can be collected. In practice the picture is much more involved with a significant number of additives available for making specific particles hydrophobic (collectors), making other particles hydrophilic (depressants), and several other classes and usages of chemical additives (Wills, 2016). Additionally, many minerals will behave differently at varying pH levels, and controlling this can permit mineral separation not otherwise possible.

Existing literature on flotation of zinc oxides is primarily focused on smithsonite ($ZnCO_3$), and it remains to be seen to what degree the body of work there is applicable to our case. (Ejtemaei et al., 2014) argues strongly that flotation is a viable option in general for zinc oxides, and that marketable zinc oxide concentrate can be made in the general case if a judicious choice of reagents is made.

The case is then made that flotation will be able to separate zinc oxides from the waste materials under consideration, but some challenges remain: Zincite and zinc ferrite is normally found only in trace amounts in natural zinc oxide deposits, and thus somewhat under-explored necessitating some lab-scale research before optimally economic commercial usage can be done. It is quite possible that research will find a suitable collector reagent which will be significantly cheaper than the current best option.

The very fine grain sizes found in EAF dust will be challenging but not prohibitive for flotation; though the resulting increased surface area will require an increased amount of collector agent (which binds to the surface of particles to be floated), somewhat increasing the cost. In the financials of the example circuit this is considered a part of the very likely inflated reagent cost used.

Separation circuit preliminary sketch

EAF Dust

A simple process design has been formulated to have a basis for financial estimation. The validity of this should not be taken for granted, as the processes are not guaranteed to work satisfactorily as is or that the financial assumptions made will hold up. The process is scaled to 10 tonnes/hour.

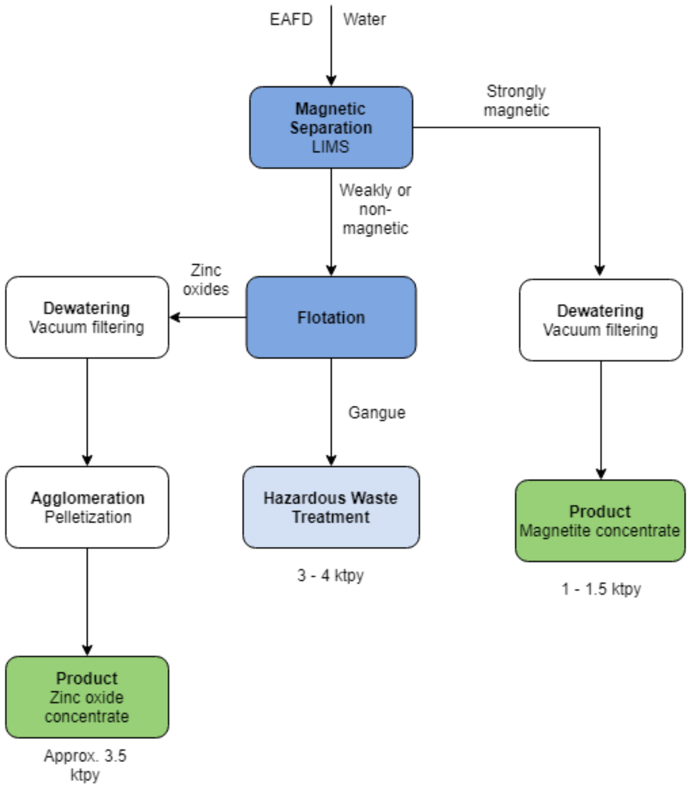

Figure 7: Preliminary EAFD circuit (also in Fig.5; repeated for convenience)

In the example process, the separation is based on removing the expected magnetite from the EAF dust before flotation, to reduce the amount going to flotation. The magnetite can quite likely be sold profitably but the price is difficult to estimate, and this has been disregarded in the financial estimate.

A list of equipment and capital requirements can be found in Appendix A5.

The flotation is based on use of Hexyl Mercaptane (HM), in previous literature noted to be effective but expensive in use – too expensive for normal use in mineral processing of low-grade ores. This has been estimated to be economically viable in this case as the EAFD is effectively a very high-grade ore. R&D should be able to find an alternative set of flotation reagents with a large potential for less costly solutions. Nonetheless, HM flotation is assumed as this remains economically viable.

The products are dewatered by vacuum filtering to a water content of approximately 12-15%, which is suitable for use in the pelletisation process.

The major assumptions here are:

- the iron oxides are found to a significant degree as magnetite – found to be the case in (Sofilić *et al.*, 2004, Machado *et al.*, 2006)
- the magnetite can be profitably sold
- the zinc ferrite is floated along with the zincite
- the zinc oxide product is usable in zinc production, especially considering the zinc ferrite

An alternative processing circuit with some further potential would be performing both low- and high-intensity magnetic separation to extract an iron oxide concentrate of hematite and magnetite. Celsa does not use iron oxides in their own production, only scrap iron and will likely not be interested in such a concentrate, but other metal producers nearby are likely able to use it.

A further alternative circuit is possible if the iron is present largely included in the zinc ferrite. If zinc ferrite is acceptable in zinc production down-stream most all zinc oxides could be concentrated by high-intensity magnetic separation followed by flotation.

Manganese sludge

At this point no process circuit will be shown, but a preliminary estimate is still made on basis of the previous sans magnetic separation, where the zinc oxide concentrate as well as the manganese-rich sludge is to be pelletized.

With the prospective scaling of 10 tonnes/hour for the EAFD process the plant is available approximately half the year. The same equipment can be thoroughly cleaned and used, except for the magnetic separators, for the manganese sludge and taking approximately three months of operation with single-shift operation 5 days/week.

Similar to the EAF process, the assumptions here are:

- the zinc is in the form of oxides in discrete (“liberated”) particles
- the zinc is mainly in the form of zincite
- the zinc oxides can be separated to an acceptable degree by flotation
- the zinc oxide product is usable in zinc production
- the flotation of zinc oxides renders the remainder usable in ferromanganese production

A2 Literature and Technology - Pilot Centres and Existing Actors

Existing actors

Valorisation plant for stainless steel and ferrochrome slag

Tapojärvi is a Finnish company specialized in factory services, mining and material handling. Tapojärvi posesses a valorisation plant for stainless steel slag that makes valuable products of by-products without any disposable waste. They are able to separate valuable metals from slag and return them to the steel factory. The rest is put to alternative use, for example "first class rock material production".

By doing this, Tapojärvi both saves money (by avoiding landfilling surcharges) and reduces their environmental footprint (by reducing the need for raw materials). Burnt lime is also separated from the slag. This way, the need of natural limestone in manufacturing of stainless steel is reduced. Tapojärvi also do valorisation of ferrochrome slag. They are able to separate and return ferrochrome from the slag so that it can be used back in the production. By performing these activities, both the company and the environment benefit (Tapojärvi Oy, 2018).

Tapojärvi appears to resemble the first stage of our own projected business case model in that the business is based on certain technologies, a specific process and a specific product.

Their own mention of avoiding landfilling taxes as an incentive is also a point of interest.

Waste Management

Waste Management is a major North American waste management business, whose business model consists of handling everything from organic household waste to industrial waste, and all underlying matters such as recycling and landfilling. The company markets itself as a paperwork-saving solution with regard to navigating through state and federal regulations, legal requirements for environmental compliance, etc. They additionally provide consulting services in streamlining and cost-cutting in industrial operations, with a focus on resource efficiency (Waste Management, 2018).

Process currently used to recycle zinc

In their recycling of EAF dust, Befesa have previously used the Waelz process which is the most common way to extract zinc oxides. This process uses a kiln, a revolving tubular furnace, where the zinc containing material is heated along with any carbon containing fuel at temperatures ranging from 1000 to 1500°C. This makes the zinc reduce, volatilize and oxidize into zinc oxide, which is then separated from the exhaust gases. (Clay and Schoonraad, 1976)

Befesa have applied the patented SDHL Waelz process at five of their EAF dust recycling sites, and this process has been acknowledged to be the BAT. In their use of this process, they first pelletize all their different zinc containing raw materials to ensure that the kiln gets a homogeneous feed. The kiln operates at a temperature of about 1200°C, and this makes all volatile elements, mainly zinc, transform into gas phase and reoxidise. The zinc oxide is then recovered by the off-gas treatment. At the end of the kiln, most of the reduced iron is oxidized into iron oxide by adding air to the charge. The heat of oxidation generated is used to preheat the entering fresh air. The SDHL Waelz process is more efficient than the classic Waelz process (Befesa, 2018b)

A3 Directives

EUs directive 2008/98/EC on waste describes basic concepts and definitions regarding waste management. It explains how to distinguish between waste and by-product and lays down a waste management hierarchy that describes the priority order when managing waste: prevention (before the product has become waste), preparing for re-use, recycling, recovery, and disposal. (European Commision, 2008)

EUs directive on the landfill of waste (1999/31/EC) took effect in 1999. The directive states that landfilling is the least preferable option and should be limited. It also describes the different categories of waste and divides landfills into three classes, landfills for hazardous, non-hazardous and inert waste. The directive set demands to the member states, in order to decrease the share of waste going to landfills. Only waste that has been subject to treatment should go to landfill (except inert waste that is not feasible to treat). (EUR-Lex, 1999)
As part of the circular economy package that the European Commission has adopted, the legislative proposals on waste will be revised. This is to simulate the transition towards a circular economy, by setting clear targets for reduction of waste and long-term path for waste management. The revised waste proposal has several key elements, of which the following two are most relevant to the metal production and processing industry; "Promotion of economic instruments to discourage landfilling" and "Concrete measures to promote re-use and simulate industrial symbiosis - turning one industry's by-product into another industry's raw material". (European Commission, 2017)

A4 Osterwalder

Innovation Norway

Company Name: NewCo
Navn på bedrift:

Date: 31.07.2018
Dato:

8 *Key Partners* / *Partnere*

- Miljøteknikk Terrateam
- SINTEF Molab
- Boliden (Zinc Purchaser)
- Celsa, Ferroglobe, Alcoa (Pilot testing, long-term contracts)
- NTNU Oppredningslaben, Sintef (Competencies)

7 *Key Activities* / *Kjerneaktiviteter*

- Landfill deposition
- By-product valorisation
- By-product testing
- Raw material sale

6 *Key Resources* / *Ressurser*

Capital requirements
Technical competencies
Network, by-product and raw material overview
Hardware

2 *Value Propositions* / *Verdiløfte*

- Complete disposal solution while assuring sustainability
- Raw material optimization

Competition:

- Befesa
- Boliden Rönnskär

4 *Customer relationship* / *Kunderelasjon*

- Utprøvde, utviklede, rel. nære relasjoner; opparbeidet tillit.
- I fremtiden: langsiktige kontrakter.
- Dra nytte av kontakter, ekspandere gj. konsern
- Goal: To be a part of the customer's value creation process

3 *Channels* / *Kanaler*

- Delivering a complete solution, enabling the customer to focus on value creating activities
- Helping customers to deliver greener, sustainable products
- Connecting existing customers, closing potential material loops

1 *Customer Segment* / *Kundesegment*

- Companies with by-product waste surplus in central Nordland
- Pilot customers: Celsa, Ferroglobe, Alcoa

9 *Cost Structure* / *Kostnader*

Equipment
Development

5 *Revenue Streams* / *Inntektsstrøm*

Capturing large parts of reutilization process in processing industry
New revenue streams through offering byproduct processing, sale of raw materials
Positioning towards zinc and carbon recovery

Figure 8: Osterwalder canvas (source: Innovation Norway)

A5 Equipment and capital costs

Table 5: Equipment and capital costs of EAF dust extraction

Equipment	**USD**		**NOK**	
Unit	Unit capital cost	Amount	Total capital cost	Comment
Mixer, small, closed tank, 73.7 cm x 2.4 m	30 570	1	kr 250 980	
Magnetic separator, 91.4 cm x 183 cm	47 300	2	kr 776 666	
Pump, 757 lpm, 15.2 m head	10 430	8	kr 685 042	
Engine, totally enclosed, 5 hp, 3600 rpm	1 349	8	kr 88 602	
Vacuum pumps, 4.25 cmm	20 530	6	kr 1 011 308	
Flotation machine, self-aerating, 1.1 m3	26 300	2	kr 431 846	
Flotation machine, column, 1.2 m, 11.3 cmm	139 230	1	kr 1 143 078	
Blower, 16.4 cmm	4 070	1	kr 33 415	
Engine, totally enclosed, 7.5 hp, 3600 rpm	1 465	2	kr 24 055	
Equipment cost			kr 4 444 993	
Additional cost			kr 2 222 496	To account for Norwegian price levels and additional equipment (e.g. feed chutes)
Sum equipment cost			kr 6 667 489	
Capital				
Machinery			kr 6 667 489	
Construction 30%			kr 2 000 247	Necessary work to install equipment in building, e.g. concrete foundation casting
Building 30%			kr 2 000 247	The building itself
Infrastructure 30%			kr 2 000 247	
Instrumentation 50%			kr 3 333 744	Installation, wiring, setup, etc of machinery
Sum			kr 16 001 973	
Unforeseen expenses			kr 3 694 500	
Sum capital expenses			kr 19 696 473	

A6 Analysis

Risk Evaluation

Table 6: Risk evaluation

Risk	Probability	Consequence	Actions
R&D discovers no feasible separation/ recovery process for EAFD and/or sludge	Low	High	Re-evaluate: Continue R&D or end project
Zinc oxide separation processes more expensive than anticipated	Medium/High, depending on magnitude	Medium/High, depending on magnitude	Streamline processes Consider alternative processes
Zinc oxide product insufficiently pure for use	Medium	High	Improve process R&D on process
Equipment costs increase significantly	Low	Medium	Find alternative suppliers Endure increased cost if necessary and economically possible
Competitors emerge nationally	Medium	Medium	Exploit all advantages MT holds in contacts, competencies
Celsa will not permit EAFD usage	Low	High	End or re-evaluate project Convince Celsa of mutual profit potential
Price of zinc decreases significantly	Low	High	Re-evaluate project Look for alternative by-products Negotiate long-term delivery contracts to mitigate risk
Nordic zinc producers unable or un-interested in buying zinc oxide product	Low	High	Look further afield

SWOT

Table 7: SWOT analysis

Strengths	Weaknesses
Provides cleaner, greener technological solutions for zinc extraction Generates and retains value in the region Generates knowledge and networks for competitive advantage in line with expected future developments (first mover advantage)	Knowledge – technological process not tried and tested in this context In need of skillsets and competencies related to mineral processing
Opportunities	**Threats**
Zero-waste regulation will lead to increased demand for by-product extraction and closing product loops Sound economical zinc extraction will lead to value capture (range of 16-28MNOK) Industry is oriented toward green solutions as expressed interest and vision statements Funding opportunities	Market uncertainty Not enough access to funding

PESTLE

Table 8: PESTLE analysis

Element	Factor	Business Impact
Political	Greater focus on material reuse Zero-waste goal leads to increased government control and incentives Globalisation trends	Greater market demand Increased uncertainty and/or tariffs lead to greater interest in local solutions
Economic	Zinc/metal price fluctuation Increased tariffs	Profitability follows zinc/metal price Higher profitability
Sociological	Greater environmental awareness and concern Greater awareness about circular economy concepts and zero waste concepts	Pressure on industry to take visible steps for increased sustainability and closing material loops
Technological	Greater available technology for by-product reutilisation and closing of material loops locally	Expansion of product offering Greater competition
Legal	National and European regulations with greater focus on by-product reutilisation Penalties for landfilling	Greater industry demand for by-product reutilisation solutions
Environmental	The proposed zinc oxide extraction is environmentally sound compared to current practice Proposed zinc oxide extraction loop happens on a local basis	Business delivers green solutions with environmental positives both during production and transport

Stakeholder analysis

Table 9: Stakeholder analysis

Stakeholder Name	Contact Person *Phone, Email, Website, Address*	Impact *How much does the project impact them?*	Influence *How much influence do they have over the project?*	What is important to the stakeholder?	How could the stakeholder contribute to establishment of NewCo?	How could the stakeholder block establishment of NewCo?	Strategy for engaging the stakeholder
MIP	Jan Gabor	Medium	Medium	Move towards a vision statement value creation through focus on environmentally friendly and energy-efficient solutions	Communicate with customers; logistical support; economical support; ownership of project as joint venture	Withdrawal of support	Monthly meetings
Miljøteknikk Terrateam	Jens Rønning	High	High	Ensure continued business in a future with landfill bans	Ownership of project as part of enterprise	Withdrawal of support	Involvement in project development Monthly meetings
Celsa	Per Johan Høgberg +4795935371 perjohan.hogberg @celsanordic.com	High	High	Ensure waste management in a more restrictive political environment re: landfills; move towards "green" vision statement;	Economical support Access to by-product	Refusal to sell EAF dust to reuse centre (continuation of deal with Befesa)	Involvement in project development; Quartery meetings
Elkem	Jørgen Hjelle	Medium	Medium	Ensure waste management in accordance to sustainable development goals			

Ferroglobe	Bjørn Heiland	High	High	-“- Access to raw materials	Economical Support Access to by-product	Refusal to use the services provided	Involvement in project development; Quartely meetings
SINTEF Molab	Eigil Dåbakk	High	High	Participation in new product loops	technical support Characterisation expertise		Involvement in project development; Quartely meetings
ACT	Marianne	Medium	Medium	Network, cluster and local innovation development	Access to network		Quarterly meetings
Rana Kommune / Rana Utviklingsselskap	Allan Berg	Low	Medium	Economic development and value creation in Rana; environmental concerns		Obstruction	Involvement in project dev. Keep informed about environmental concerns
Boliden Odda	+47 53 64 91 00 info.odda@boliden.com	Medium	Medium	Value capture opportunity	Express interest in purchasing zinc oxide	By not purchasing zinc oxide	Active approach to engage as zinc oxide customer
Boliden Kokkola	+358 6 828 6111 info.kokkola@boliden.com	Medium	Medium	Value capture opportunity	Express interest in purchasing zinc oxide	By not purchasing zinc oxide	Active approach to engage as zinc oxide customer
Rana Blad		Low	Low	Sell newspapers Community engagement	Positive coverage	Negative coverage	Keep informed, Approach environmental concerns diligently Focus on local wealth creation
Miljødirektoratet		Low	High	Project in line with regulations	Grant permit	Deny permit	Approach environmental concerns diligently
KPH	Monica Paulsen	Medium	Medium	Innovation and development in Helgeland	Networking, grant access, consultancy re: tax issues	No interest in blocking the project	Quarterly meetings; Project updates
Nordland Fylkeskommune		Low	Low	Value creation in Nordland	Capital incentives		
NTNU Oppredning	Rolf Arne Kleiv, Erik Larsen	Low	Medium	Mineral processing advances, research	Consultancy; technical support	No interest in blocking project	

Alcoa Mosjøen	Maren Seljenes Bøe	Medium	Medium	To find an alternative use for their filter dust	Providing filter dust for testing and treatment	Not providing filter dust	Involvement in project development; Quarterly meetings
SINTEF/SINTEF Helgeland	Jack Ødegård	High	High	Insight in industrial challenges and by knowhow propose the good solutions	perform relevant R&D and ensure its industrial implementation (Innovation)	Restrict the needed knowledgebase	Continuous dialogue with industry stakeholders and promote relevant public support/funding mechanisms

A7 Cash Flow Projections

Table 10: Cash flow projections

	2019	2020	2021	2022	2023	2024	2025
Cash Receipts							
Zn Sales Income	0	0	0	28 324 500	28 324 500	28 324 500	28 324 500
Sludge valorisation income				3 712 562	3 712 562	3 712 562	3 712 562
R&D funding income	600 000	1 800 000	0	0	0	0	0
Total Cash Receipts	**600 000**	**1 800 000**	**0**	**32 037 062**	**32 037 062**	**32 037 062**	**32 037 062**
Cash Payments							
Process Costs				8 831 462	8 831 462	8 831 462	8 831 462
Additional Sludge valorisation process costs				6 003 853	6 003 853	6 003 853	6 003 853
R&D	1 500 000	4 500 000					
G&A							
Wages Process				1 500 000	1 500 000	1 500 000	1 500 000
Wages Management	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000	1 200 000
Freight Out				1 012 000	1 012 000	1 012 000	1 012 000
Other Transport				175 000	175 000	175 000	175 000
Storage and Cache				125 000	125 000	125 000	125 000
Landfilling				3 600 000	3 600 000	3 600 000	3 600 000
Investment in Plant, Property and Equipment							
Machinery			4 444 993				
Construction 30%			2 000 247				
Infrastructure 30%			2 000 247				
Instrumentation 50%			3 333 744				
Site construction 30%			2 000 247				
Unforeseen expenses			3 694 500				
Total cash payments	**2 700 000**	**5 700 000**	**18 673 977**	**22 447 314**	**22 447 314**	**22 447 314**	**22 447 314**
Net Income Before Taxes (EBIT)	**-2 100 000**	**-3 900 000**	**-18 673 977**	**9 589 748**	**9 589 748**	**9 589 748**	**9 589 748**
Accumulated Cash Flow Before Tax	**-2 100 000**	**-6 000 000**	**-24 673 977**	**-15 084 229**	**-5 494 482**	**4 095 266**	**13 685 014**

A8 Potential Funding Support

Environmental Technology Scheme (Miljøteknologiordningen)

The Environmental Technology Scheme («Miljøteknologiordningen») offers public funding for the construction of pilot- and demonstration plants that exhibit new, more sustainable technological solutions than the currently conventional and used standards. The scheme is funded and run by Innovation Norway (Innovation Norway, 2018).

The scheme is focused on two general lines of support:

- 1. Development, production and testing of new sustainable solutions in pilot- and demonstration phases
    - The applicant company owns and will run the project themselves
    - The applicant has typically developed the solution themselves
- 2. Demonstration of climate and environmental solutions in large scale:
    - 2.a Funding for increased costs related to demonstration of new solutions which represent a more environmentally sustainable approach than current norm and EU regulation
    - **2.b Funding for increased costs related to investments where new solutions for reuse or recycling of waste are trialled. Applicants who intend to treat waste or surplus materials from other companies are supported under this sub-scheme**

Projects under scheme 2.b can be receive public funding for up to 35 %, 45 %, or 55 % of the cost for large, medium and small companies respectively.

To gain funding from this scheme, the applicant must be a well-established business or a young business under 5 years. Newly established businesses do not get funding from this scheme.

An example of a project funded by the Environmental Technology Scheme is ongoing at the Alcoa test plant in Lista (Miljøteknologiportalen, 2018). The project is investigating the possibility of using a known process in a new way to produce aluminium in a way requiring significantly less energy with corresponding reductions in gas emissions if adapted in aluminium plants that run on fossil energy sources i.e. most outside Norway.

LIFE program, EU

The LIFE program is the EU's funding instrument for the environment and climate action. The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value. Since its beginning in 1992, LIFE has co-financed some 3954 projects across the EU, contributing approximately €3.1 billion to the protection of the environment. The European Commission (through DG Environment and DG Climate Action) manages the LIFE program but has delegated the implementation of many components of the LIFE programme to the Executive Agency for Small and Medium-sized Enterprises (EASME). The European Investment Bank will manage the two new financial instruments (NCFF and PF4EE) (European Commission, 2018b). The LIFE program sponsors projects in a variety of fields relevant to environmental and climate issues, including projects involving circular economy concepts in the metal industry and non-metallic minerals industries (European Commission, 2018c, European Commission, 2018d).

The by-product valorisation centre as proposed in its present form does not satisfy the criteria for LIFE eligibility, as the coordinating beneficiary must be registered in the EU. However, associated beneficiaries can be legally registered outside the EU. These associated beneficiaries must be responsible for one or more project actions that are necessary for achieving the environmental objectives for the EU, and must contribute financially to the project (European Commission, 2018a).

Horizon 2020

Horizon 2020s Societal Challenge 5 is EUs funding program on climate action, environment, resource efficiency and raw materials (European Commission). This is a funding program for research and innovation that

1. achieve a resource efficient and climate change resilient economy and society
2. support protection and sustainable management of natural resources and ecosystems
3. follow sustainable supply and use of raw materials that meet the growing global population within sustainable limits

This is a collaborative funding, meaning collaboration between at least 3 partners (businesses, universities or other institutions). Most projects have 5-8 participants with a budget of 2-10 million euros. For financed cooperative projects, participants usually get 70% of project costs financed. Some activities even get 100% financed project costs. To get funding, one need to precisely match a topic within Horizon 2020 (Innovayt).

SkatteFUNN

SkatteFUNN is an incentive that has the goal of motivating Norwegian industry to increase their commitment to R&D. This is for projects that create value based on new ideas that can give better products, services or production methods. The funding scheme that gives businesses up to 20% tax deduction on costs related to R&D for small and medium sized businesses (Norges forskningsråd, 2017).

A9 "Gjenova"

Enova and the low emission future

Enova is a Norwegian state owned organization that provides consulting and funds for Norwegian projects that use new and climate friendly technology, through management of Energifondet. This fund generates its income from a fee on electricity as well as through the National Budget. The kinds of technologies funded are mostly related to energy and emissions. Enova funds all kinds of projects, ranging from commercial to household, but primarily target large industrial enterprises with large power consumption. In 2017, Enova funded projects with over 2 356 MNOK, distributed to 931 corporate actors and 8123 private households. Enova's CEO Nils K. Nakstad states that the projects that are important for them, are the projects that have the strongest potential for change and can guide us towards a low emissions society. Enova operates on a long-term perspective (Enova, 2018).

The zero-waste future

From an energy efficiency and climate perspective, Enova has been a success in aiding industrial companies with high power consumption to enter a low-emission future. With today's focus on material usage and entering a circular economy, one might think that there are similar programs in place for industries with high material wastage, in order to help them become more material efficient and sustainable. Unfortunately, this is not the case.

The program that is closest to cater to these needs is Miljøteknologiordningen, which funds both pilots and full-scale demonstration projects on climate and environmental solutions. The program focuses on contractors and their production technology. Miljøteknologiordningen is a part of Innovation Norway and not an independent support organization like Enova, which limits the total amount of supported projects. Miljøteknologiordningen had 550 MNOK available in 2017 compared to Enova's 2 356 MNOK. Miljøteknologiordningen also aims wide on many types of environmental technologies on climate, energy efficiency, pollution and material efficiency. This gives the projects on material efficiency higher competition, resulting in fewer supported projects (Innovation Norway, 2018).

In order to meet a more sustainable future, a more efficient material usage is on order. To continue present practice is simply not sustainable in the long run. We find there is a missing link between the existing supporting schemes and the vision of entering a circular economy and sustainable future. There is a pressing need for bigger and better tools in society's and the industry's toolbox, in order to create a green and sustainable industry while maintaining competitiveness.

Proposal: "Gjenova"

The concept of a "Gjenova" based on the Enova-model was proposed for Stortinget by four members of parliament in 2005 (Heidi Sørensen et al., 2005), but the politicians did not take the proposal further, despite being a part of the "Soria Moria declaration" in 2005 (Stoltenberg et al., 2005). In the declaration, it was stated that the government would create a state-owned enterprise for waste prevention and recycling. The proposal met resistance from many ministries, including the Ministry of Finance, so this was never initiated[25]. It is

[25] From conversation with Heidi Sørensen

worth mentioning that in 2005, the concept of circular economy was not known for many people, and with regards to that aspect, the proposal may have been "ahead of its time".

We, too, propose an introduction of a "Gjenova" based on the Enova model. Enova was established to help businesses become a part of a low emission future, while "Gjenova" would be established to help businesses enter a zero-waste future. "Gjenova" would fund projects that makes the material use of businesses more efficient in the same way that Enova funds projects that is focused on energy efficiency. The main focus group could be large industrial actors with high material usage, similar to those with a large power consumption that get support from Enova. Enova is financed by a fund that generates income from a fee on electricity as well as through the National Budget. "Gjenova" could be based on the same model with financing by a fund that generates income from the final treatment tax of waste or possibly through a future tax on landfills (referring to Tapojärvi in Appendix A2).

Table 11: Comparison between Enova and "Gjenova"

Enova	**"Gjenova"**
Helping businesses enter the *low emission future*	Helping businesses enter the *zero-waste future*
Focuses on increases in *energy* efficiency	Focuses on increases in *material* efficiency
Targets businesses in all sizes but mainly large industrial actors with *large power consumption*	Targets businesses in all sizes but mainly large industrial actors with *high material wastage*
Supports the projects that have the strongest potential for change and can guide us against a *low emission society*	Supports the projects that have the strongest potential for change and can guide us against a *zero-waste society*
Financed by a fund that generates income from a *fee on electricity*, as well as through the National Budget	Financed by a fund that generates income from the *final treatment tax* or *a possible future landfill tax*, as well as through The National Budget

We believe that introducing a "Gjenova" could have a positive impact in the same way Enova has, making Nakstad's words also come true for a zero-waste future. The projects with strongest potential for change will lead the way.

A10 Gantt diagram of proposed future development

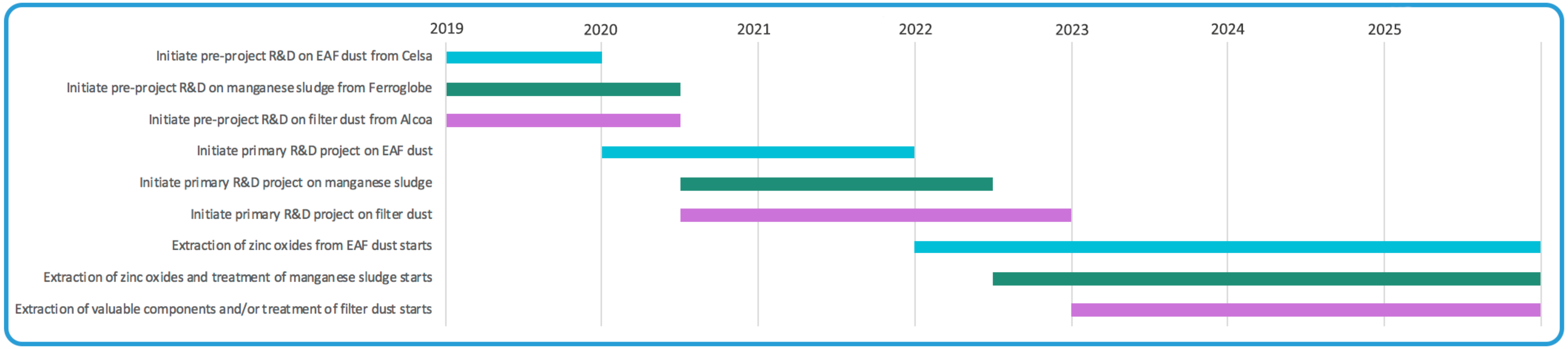

Figure 9: Gantt diagram of proposed future development

A11 An estimate of the CO_2 footprints

An estimate of the total CO_2-equivalent emissions related to transporting and converting EAF dust to zinc metal is performed for today's solution as well as for the proposed local solution. The results are shown in table 13 by tonnes CO_2-equivalent per tonne EAF-dust transported and processed. The assumptions and sources that are used in these calculations are shown in Table 14.

Basis for calculation

The transportation and processes with an environmental impact that are used in the calculation of CO_2 are shown in table 12.

Table 12: CO_2-generating processes as basis for calculation of CO_2 footprint

Today's solution	**Proposed solution**
1. Transportation of EAF dust with boat from Mo i Rana to Antwerp	1. Zinc oxide extraction from EAF dust locally
2. Transportation of EAF dust with lorry from Antwerp to Duisburg	2. Transportation of zinc oxide from Mo i Rana to Odda by boat
3. Zinc oxide extraction from EAF dust in Duisburg	
4. Zinc oxide to zinc processing in Germany (transportation neglected)	3. Zinc oxide to zinc processing in Odda

Results for today's processing

Total emissions estimated to *2,35 tonne CO_2-equivalent per tonne EAF dust* transported and processed. The main contributor is the processing which stands for 98,3% of the emissions.

Results for local processing

Total emissions estimated to *0,06 tonnes CO_2-equivalent per tonne EAF dust* transported and processed. 83% of the emissions comes from processing and 17% comes from the transportation.

Total emission reduction

As the results shows, the total CO_2-emissions are estimated to be *reduced by 2,29 tonnes CO_2-equivalents per tonne EAF dust* processed with the local solution. With 8000 tonnes EAF dust per year, this is equivalent to 18 320 tonnes CO_2 reduced each year.

Comment on uncertainty

The number with highest uncertainty is process 4 in today's solution in table 13 and 14, with the assumption that 40% of all energy consumption in the life cycle of Zn is from converting ZnO to Zn. The rest of the numbers are based on academic research and recommendations, including an EPD along with some assumptions. Boliden Odda has also taken several environmental measures that can introduce a difference in energy consumption.

Table 13: Results per tonne EAF dust transported and processed

Today's solution		Local solution	
Process	**CO_2 equivalent [tonnes]**	**Process**	**CO_2 equivalent [tonnes]**
1. Transportation, boat	0,03	1. ZnO extraction	0,002
2. Transportation, lorry	0,01	2. Transportation, boat	0,01
3. ZnO extraction, WAELZ	0,74	3. ZnO to Zn in Norway	0,05
4. ZnO to Zn in Germany	1,57		
Total	**2,35**	**Total**	**0,06**

Table 14: Assumptions and comments in calculation of emissions

	Assumption	**Comment/Source**
CO_2 per kWh electricity in Germany	511 g	(RE-DISS, 2015)
CO_2 per kWh electricity in Spain	309 g	(Moro and Lonza, 2013)
CO_2 per kWh electricity in Norway	17 g	(NVE, 2016)
CO_2 per km-tonne with boat	16 g	Recommended numbers by (McKinnon and Piecyk, 2010)
CO_2 per km-tonne with lorry	62 g	
CO_2 per km-tonne with train	22 g	
ZnO fraction in EAF dust	55 %	Test results from Hidronit in Barcelona
Efficiency of local and WAELZ process	Equal	
Distance with boat from Mo i Rana to Antwerp	1937 km	Marinetraffic.com
Distance with truck from Antwerp to Duisburg	179 km	Google Maps
CO_2 per tonne dry dust in Waelz in Spain	0,53 tonne	(Befesa Zink Aser, 2016)
CO_2 correction factor for Waelz plant in Germany (vs Spain)	1.4	Accounting for higher CO_2 in German electricity (vs Spain)
Life cycle energy usage of zinc	14 kWh/kg	(International Resource Panel, 2013)
The fraction of life cycle energy consumption of zinc that is ZnO to Zn conversion process	40%	Assumed 40% of total energy usage in zinc life cycle is in the process converting ZnO to Zn
Distance from Mo i Rana to Odda by boat	1038 km	Marine Traffic, Google Maps
Local zinc oxide extraction energy consumption	250 kWh/tonne ZnO out	Based on (Kleiv, 2017) and assumptions

A12 EAF Zinc value estimate assumptions

Several assumptions and estimates (listed underneath in table 15) were made to arrive at the values given in table 16.

Table 15: Assumptions and estimates in zinc oxide product value estimation

Parameter	Value	Comment/source
Zinc assay (content)	35 – 40 %	Based on comments of Jens Rønning
Net Smelter Return	50 %	This is the fraction of the pure metal price a “mine” will get when selling to a smelter. Based on rule of thumb expressed by Wellmer (Wellmer, 2008).
Metal price, very low	1500 USD/tonne	Judgment call based on 5-year zinc price chart, seen below
Metal price, low	2000 USD/tonne	
Metal price, mid	2500 USD/tonne	
Metal price, high	3000 USD/tonne	
Metal price, very high	3500 USD/tonne	
Zinc recovery	75 % Low 85 % High	Judgment call based on results in available literature.
USD/NOK exchange rate	8.21 NOK/USD	As of 19.07.18

Figure 10: 5-year zinc metal prices. Source: infomine.com

Table 16: EAF value estimates. Variables are the Zn content, how much of it is recovered, and the obtainable zinc oxide price respectively

Scenario	Income
Assay/recovery/Zn price	NOK/year
Low assay, low recovery, very low	kr 12 930 750
Low assay, low recovery, low	kr 17 241 000
Low assay, low recovery, mid	kr 21 551 250
Low assay, low recovery, high	kr 25 861 500
Low assay, low recovery, very high	kr 30 171 750
High assay, high recovery, very low	kr 16 748 400
High assay, high recovery, low	kr 22 331 200
High assay, high recovery, mid	kr 27 914 000
High assay, high recovery, high	kr 33 496 800
High assay, high recovery, very high	kr 39 079 600