2021:00461- Unrestricted

# Report

## Aluminium packaging flows in Norway

Overview and challenges

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2021-04-26

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KEYWORDS:
Keywords

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| VERSION | DATE |
|---|---|
| 01 | 2021-04-29 |

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| PROJECT NO. | NUMBER OF PAGES/APPENDICES: |
|---|---|
| 102020702 | 28 |

**ABSTRACT**

This report gives an overview of aluminium packaging flows in Norway illustrated with diagrams where the metal flow arrows are proportional to the tonnage between distinct collection/processing steps. The results show that most of the used beverage cans are collected through the deposit system. The municipal collection system for food packaging on the other hand, collects only half of the metal products put on the market. The other half goes into the household waste bins.

The report also evaluates the quality after remelting of used beverage (in general) and food packaging (case study). Infrastructure of the recycling system in Scandinavia are further described. A discussion of sorting versus incineration are provided.

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| REPORT NO. | ISBN | CLASSIFICATION | CLASSIFICATION THIS PAGE |
|---|---|---|---|
| 2021:00461 | 978-82-14-07661-5 | Unrestricted | Unrestricted |

# Document history

| VERSION | DATE | VERSION DESCRIPTION |
|---|---|---|
| 01 | 2021-04-26 | First version. |

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## Definitions and abbreviations

**EPR (Extended Producer Responsibility) –** a practice and a policy approach in which producers take responsibility for management of the disposal of their products after EoL. Responsibility for disposal may be financial, physical, or a combination of the two.

**MRF (Material Recovery Facility) –** A centralized facility collecting and sorting waste streams and eventually selling it to end-use manufacturers.

**Bottom ash –** The waste remaining after incineration contrary to fly ash that goes up the stack in the incineration plant.

**Municipal waste –** Household waste which is generated daily.

**Rotary furnace –** Rotating drum furnace used to melt aluminium scrap and dross. Uses salt to improve yield.

**RVM (Reverse vending machine) –** Machines where you deliver PET-bottles and UBC's and get a payment-reward for delivering them.

**UBC (Used Beverage Cans) –** often made of aluminium.

**PET (PolyEthylene Terephthalate) –** The type of plastic beverage bottles are made of today.

**Deposit-refund system –** A system implemented in Norway where a deposit is included in the products price. The deposit is refunded, when the cans and bottles are returned to the reverse wending machine.

**EoL (End of Life)** – A product that has reached the end of its useful life.

**Sankey diagram –** A type of flow diagram where the arrows are proportional to the flow in the unit used.

**Downgrading –** The value lost due to loss in metal quality and alloy specifications.

**Wrought alloys –** Aluminium alloys made for extrusion, rolling and other types of plastic deformation.

**Cast alloys –** Aluminium alloys made for casting.

**LCA (Life Cycle Assessment) –** Standardised method looking at the environmental impact of the life cycle of a commercial product.

**NMG (Norsk Metallgjenvinning) –**A Norwegian EPR company with responsibility for assisting the collection and recycling of end post-consumer metal packaging.

**SSB (Statistisk SentralByrå) –** Statistics Norway is the national statistical institute of Norway and the main producer of official statistics

# 1 Introduction

Aluminium is known to be a highly recyclable material often said to be infinitely recyclable. Aluminium today is still, however, far from being 100 % recovered. Full collection - in Norway or worldwide - does not exist. Aluminium also faces challenges in terms of mass losses during processing and alloy specifications after being recycled. This must be dealt with every time aluminium goes through the recycling loop.

This report focuses on the End of Life (EoL) aluminium from food and beverage packaging and specifically the system in Norway. An overview of flows is generated and the challenges regarding metal quality discussed. Norwegian recycling systems, regulations, labelling, and measures needed to improve overall recycling performance is also commented.

## 1.1 Motivation

The motivation behind this report is to get a better understanding and overview of material flows and recycling of aluminium food and beverage packaging in Norway. By mapping these flows and identify sections that may be improved, optimization of the process will be easier. Economic concerns must, of course, also be considered.

## 1.2 Background

Aluminium is used in food packaging due to its good preservation properties. Aluminium works as a barrier against oxygen and light; both of which reduce the quality of food products. The food products on supermarket shelves are fast-moving consumer products with a relatively short shelf-life. Most food products are packed in disposable packaging. This results in a large and continuous flow of used packaging materials, which needs processing.

Secondary production of aluminium, i.e. recycling, is a more resource and environment friendly approach than extracting aluminium from ore. The energy use is approximately 5 % compared to primary production. Metals, including aluminium, have a high monetary value compared to other materials (e.g. glass and plastic). Consequently, there is a strong economic motivation to recycle besides concerns about sustainability. A high value on aluminium also allows that upcycling steps (e.g. sorting) can be added to process and still be economical viable.

Generally, one can say that metals do not know their origin, that is if it comes from primary or secondary metal. The main concern is primarily the alloy chemistry of the original aluminium. The end alloy is a blend of the remelted scrap (including liquid primary metal if the casthouse is in conjunction with a primary plant). However also, the shape and contamination of the scrap matters when it comes to metal quality. Pieces that are small and dirty are more challenging to recycle than those that are large and clean. The remelting methods as well as refining methods and casting in the end of the process, contribute to the quality of the final product.

The recyclers tailor their tools and processes in the casthouse to meet their customers' specifications. These specifications are determined by the final mechanical properties of their end product, such as car wheels and new beverage cans. Customers also specify end quality measures, for instance limits of dissolved hydrogen or maximum number of particles per kg metal together with the chemistry window of the alloy. Sometimes customers specify melt treatments such as gas purging and filtration.

In this study we focus on the material the remelters get from collectors of food and beverage containers. However, these remelters also use bottom ash aluminium originating from among others incinerated packaging. Bottom ash aluminium recycling is therefore also briefly discussed in the report.

The overall goal is getting the most value (economic & environmental) out of the scrap. This is a core part of moving towards a circular economy and a more sustainable future. Both those concepts include the important task of avoiding suboptimization and thus improving recycling.

## 1.3 Scope

This report will include a general overview of the flows of aluminium from EoL food/beverage packaging in Norway. Other types of scrap will not be considered in this study. The various paths of used aluminium packaging and their processing steps will be discussed.

In Norway there are three main paths for EoL aluminium beverage and food packaging defined by the point of collection:

1. Recycling via collection scheme for used beverage cans (UBC), see section 2.2
2. Municipal collection systems: a combination of curbside collection at individual households and communal recycling points, see section 2.3
3. Household residual waste that go to incineration, see section 2.4

This study will mainly deal with these three material streams and a major part of the report include the overview and mapping of what happens with the aluminium in the respective streams, how they are connected, and the total amount of aluminium involved in these loops every year. Collection of waste and consumer behaviour towards recycling falls beyond the scope of this study and has previously been reported by Bækken [1] .

Process description of the steps in the three loops is also described in the report. There are several different aluminium alloys used in beverage and food packaging. That means when several alloys are mixed and melted together, downgrading is likely the result. A general overview of downgrading and its significance is therefore discussed in the report. Also, general refining solutions and examples of dilution solutions are mentioned. In terms of design and labelling, this would certainly be interesting to investigate on a deeper level, but this is beyond the scope of this project and will therefore not be discussed, except for one example.

## 1.4 Method

This report is mainly based on other reports written by institutes and trade organisations, websites, articles, and direct contact with the industry involved. Data and numbers are taken from official numbers from annual reports, statistics Norway (SSB) and information received directly from the industry. The data and information are presented thematically. Data were also analysed using Sankey diagrams, se section 2.5.

# 2 Material flow of aluminium packaging in Norway

As mentioned in section 1.3, there are three paths for End of Life (EoL) food packaging consisting of aluminium. The paths are different in terms of yield, quality, and convenience for consumer and for companies involved. These three will now be described in more detail.

## 2.1 Overview

The flow of aluminium packaging is complex, and there are many institutions and companies involved in different steps of the value chain. A simplified overview of used packaging materials flows can be seen in Figure 1.

1: Deposit recycling for used beverage cans (UBC) with Infinitum and Hydro as main players

2: Municipal collection systems recycling involving Norsk Metallgjenvinning and Metallco and

3: Household residual waste that goes to incineration.

A detailed look into these material flows, which both shows material flow and flow of communication between the companies/institutions is described in the following sub-chapters.

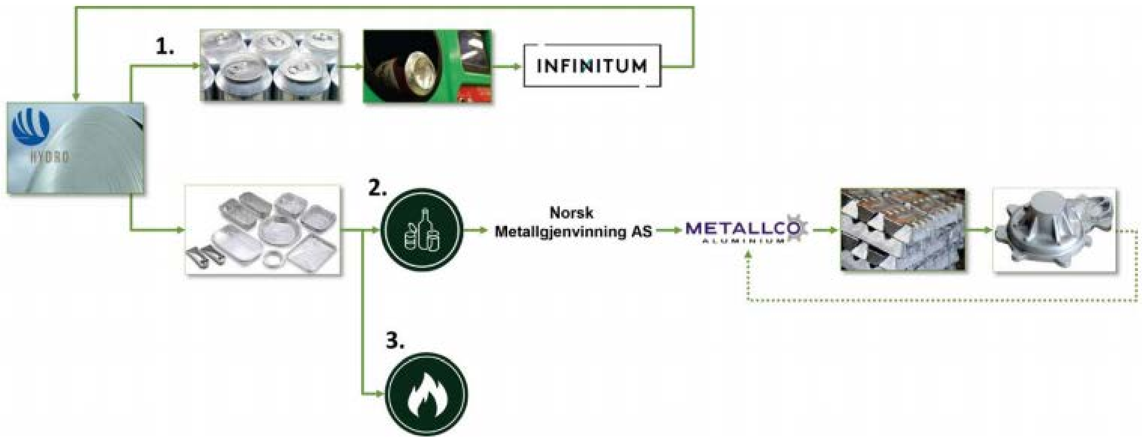


**Figure 1: Simplified sketch of flows and companies involved in recycling of Al-packaging in Norway.**

## 2.2 Deposit recycling (beverage cans)

The beverage can material flow is, in many ways, the success story of aluminium recycling in Norway. All aluminium cans and PET bottles for beverage introduced into the Norwegian market from the members of Infinitum (see section 4.1) is part of a deposit-refund system also known as “pantesystemet”. Until August 2018 beverage bottles (beer and soft drinks) made of glass and tapped in Norway were also part of the deposit-refund system. This system is quite simple: the consumer pays a deposit when buying the beverage and gets it back when delivering the empty container through reverse vending machines in supermarkets, or manual return points in smaller shops or kiosks.

The deposit system is operated by Infinitum, a Norwegian privately owned company that operates the infrastructure and have their own plants for processing the used beverage packaging. The reverse vending machines are designed and produced by Tomra or RVM Systems and are placed in most retail stores in Norway making it convenient for consumers to return their empty cans. These machines calculate the payment rewarded to the consumer based on bar codes marked on the cans, and they press the cans into more compact shapes for transport. The pressed UBC’s are collected by the food delivery trucks after they have delivered food and other goods. This saves transport as these trucks would have returned to logistic hubs anyway. Intermedia transport then deliver the UBC’s to Infinium’s three plants close to Narvik, Oslo and Trondheim. At these Infinitum facilities plastic and metal beverage containers are separated. A magnet is removing steel beverage cans. After sorting the used beverage containers are pressed and baled. These baled UBC's are sent to Hydro Holmestrand for remelting in rotary furnaces. These furnaces use a salt flux. Hydro Holmestrand produces wrought aluminium and various rolled products, ranging from instance aluminium cladding for the building industry to food packaging containers (but not beverage cans).

In 2019, 684 093 737 cans were introduced to the Norwegian market of which 598 643 369 cans were returned to the reverse vending machines. This makes an 89,5 % collection rate of UBC’s through the reverse vending machines, which is the best collection rate for the deposit-refund system to date.

## 2.3 Municipal collection systems recycling (metal food containers)

In Norway today municipalities operate two collection systems. A *home collection* system, whereby a bin for glass and metal packaging is placed at households or *public collection* points which are spread throughout the municipality. Approximately 50% of Norway is covered by home collection systems. Most municipalities are expected to follow to home collection in the coming years.

Norsk Metallgjenvinning are responsible for metal packaging. Sirkel Glass are responsible for the glass packaging. *Sirkel Materialgjenvinning* process and sort glass and metal packaging. The material collected from Norwegian municipalities is (exclusively) sent to the Sirkel Materialgjenvinning AS plant at Øra outside Fredrikstad. At this plant, the metal and glass are sorted in different steps illustrated by a general drawing in Figure 2 and a general description:

1. Various types of magnets – removing magnetic metal.
2. Eddy current separator – separating nonferrous metal into a fraction.
3. Crusher – to break and thereby liberate glass that are physically trapped in the nonferrous metal pieces.
4. More sorting of the non-metallic metal using various techniques.

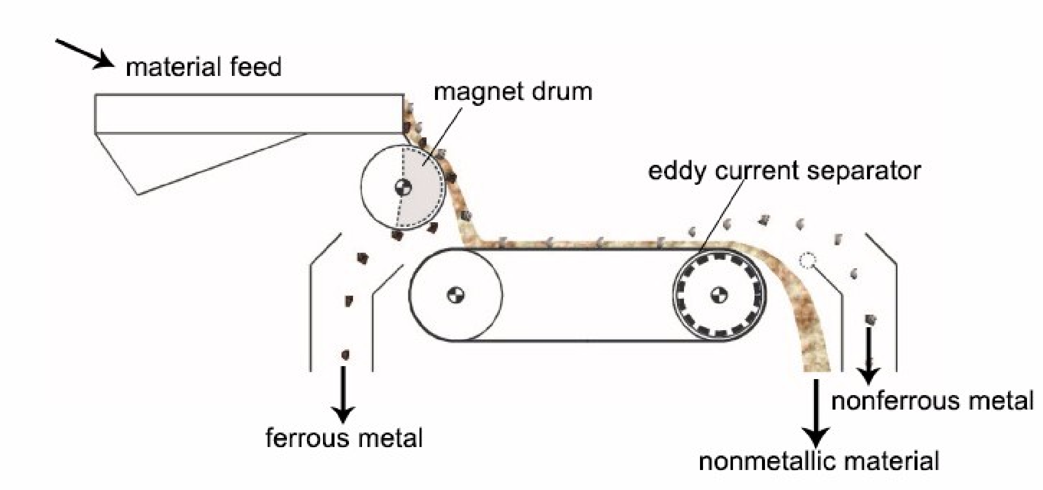


**Figure 2: Schematic of sorting facility where the material is split into ferrous (magnetic), non-ferrous metal (non-magnetic), and non-metallic material. [2]**

This sorted aluminium fraction is sent to the scrap dealer Metallco AS at Alnabru for pressing. Metallco AS also owns a remelter, Metallco Aluminium, at Eina. This plant has been remelting aluminium for 30 years producing foundry alloys. By installing a rotary furnace, they are now also able to test remelt used food cans from NMG (see section 3.5).

## 2.4 Incineration (household waste)

Some of the aluminium used in packaging materials end up in the residual household waste bins; together with materials that are not defined as packaging such as aluminium foil. Aluminium from packaging ends up in this stream when consumers make sorting mistakes, and when the packaging solution consist of several materials, e.g. laminates of plastic or cardboard. It could simply also be because of large amount of food residue, convenience, and lack of metal recycling bins nearby. Confusion regarding certain products, such as the before mentioned aluminium foil, could also be a reason.

What happens to the household waste varies depending on where in Norway you are and the local waste management company's protocols. This makes getting an overview of this stream more difficult than the two previous ones. There are a few material recovery facility (MRF) sorting plants that are sorting household waste into recyclable fractions before incineration. These include IVAR outside Stavanger, ROAF in Oslo and a planned one called SESAM outside Trondheim. However, in most places today the household waste goes directly to an incineration plant. The waste remaining after incineration are named bottom ash, contrary to fly ash that goes up the stack in the incineration plant. Some household waste is also exported to Sweden for incineration [3].

The bottom ash contains a considerable amount of metals, with aluminium as a significant portion. Small gauges aluminium however is oxidised significantly. The yield of aluminium through the incineration plant is in a study estimated to be 62%. The remaining 38% is lost by oxidation or not being sorted out of the bottom ash. [4]. This is considered as material loss only. The quality of the remaining metal is an important factor that also needs to be taken into account.

Removal of metal from the waste is done both before and after incineration. Under pre-treatment most of incineration plants have a magnet to remove magnetic metals. After incineration both magnetic and non-magnetic metals are sorted out from the bottom ash [4]. In terms of difficulty, the smaller particles are more difficult to extract than the large ones. The smaller particles would also face more problems later as these oxidize more in the remelting step.

The aluminium sorted out from the bottom ash is sent to various places depending on the incineration plants. However, it seems that the majority stays in Scandinavia as most of the agreements seems to be between Norwegian, Swedish, and Danish companies. Additionally, there are also some contracts with UK companies. Bottom ash aluminium is further processed and eventually compressed at these 3$^{rd}$ party companies. A national system for the incineration and further processing of bottom ash would make it more traceable and easier to gain knowledge about the overall value chain. However, the amount of bottom ash and current infrastructure does not seem to allow this.

Norwegian companies such as Hydro and Metallco buy bottom ash from the 3$^{rd}$ party companies that Norwegian incinerator plants sell to.

## 2.5 Al flows diagrams in Norway (Sankey)

In Sankey diagrams the width of the arrows is proportional to the flow quantity, the larger the width of an arrow, the larger the material or energy flow. The arrows show flows from one point to another point also clarifying the process steps or value chain of the system involved. It is named after Captain Matthew Sankey, who in 1898 used this type of diagram to show the energy efficiency of a steam engine.

Sankey diagrams are a useful tool to illustrate the flow of aluminium from food / beverage packaging in Norway. In the flow diagrams below the arrows are proportional to the quantity of materials, the circles represent steps in that flow.

### 2.5.1 Assumptions

To develop the models a few assumptions had to be made and the data also include uncertainties that should be considered when looking at the results. These include:

- Different data sources were used and some discrepancy in the numbers from the different sources were found.
- Statistics Norway (SBB) numbers especially seem to be very high, which could be a result of including organics and other residues in the counting of metals.
- Statistics Norway (SBB) numbers are from 2018 but all the others are taken from 2019. They are still included in the diagram as we assume that the flow is the same in 2019 as it was in 2018.
- In the analyses certain material losses were neglected or dismissed due to lack of data.
- It is assumed that the beverage cans sold in Norway consists of 100% aluminium alloys, no steel cans. It is also assumed that other beverage cans introduced to the Al-streams in Norway also consists of 100% aluminium alloys.
- It is assumed that there is no aluminium metal ending up in landfill.

The data came from different sources who may have used different standards for measurements. This leads to an unavoidable degree of uncertainty, and must be considered when looking at the obtained results. It should also be mentioned that there is a risk that certain streams could be counted twice or not at all. This would certainly affect the results, and that we have been keenly aware of and tried to avoid when investigating the necessary data.

Generally, the numbers originating from Statistics Norway involves more uncertainty than the other numbers. They are based on picking analysis from waste, as opposed to online scanning of every single used beverage can, which is in the other end of the trustworthy number scale. The numbers from food packaging comes from self-reporting of members of Norsk Metallgjenvinning and is likely in the middle of this scale.

### 2.5.2 Sankey diagrams

Figure 3 shows a simplified Sankey-diagram of the aluminium material flow in Norway, while Figure 4 includes cross flows and a stream from other sources. These two figures are shown om the following pages.

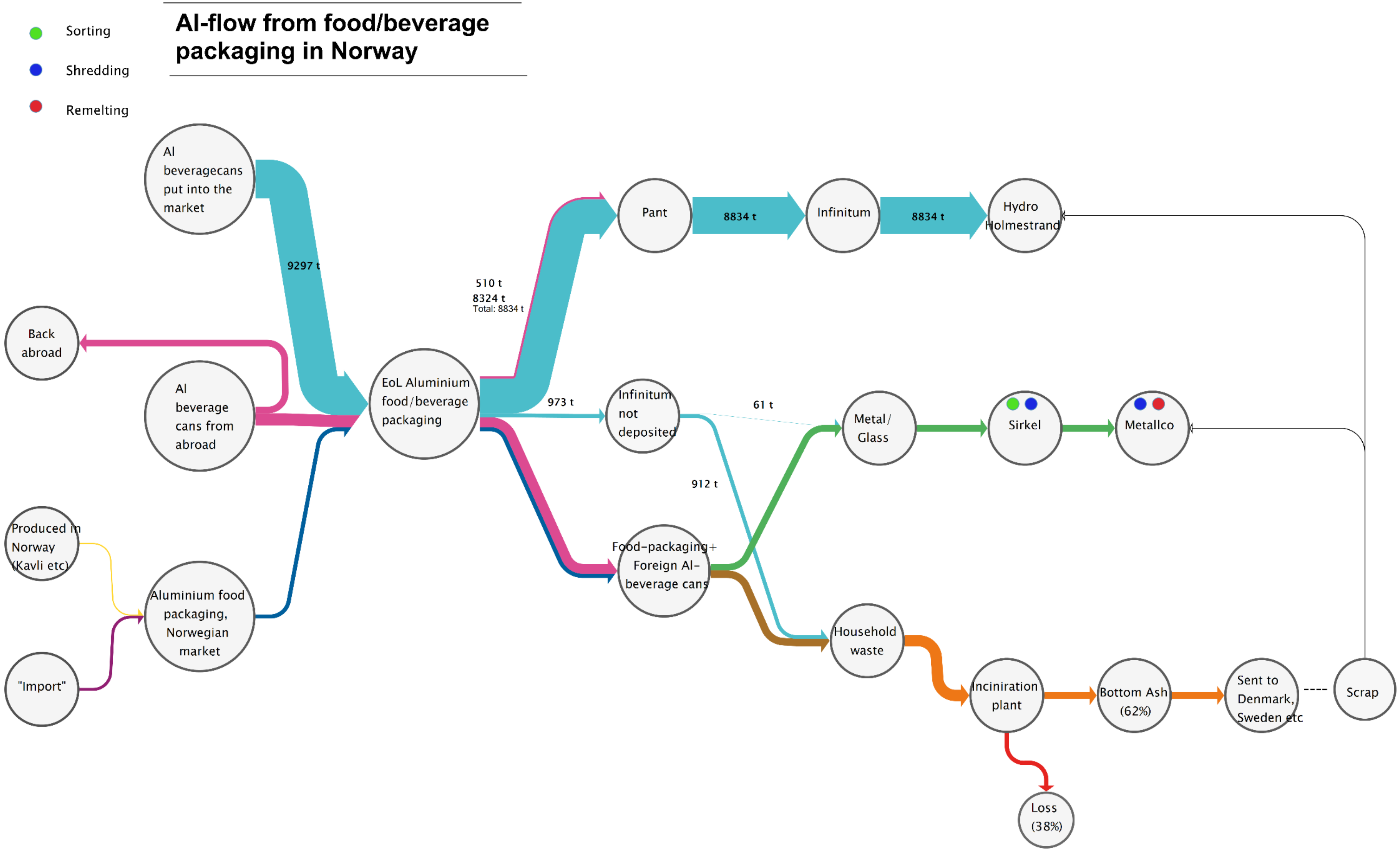


**Figure 3: Simplified diagram of the Al-packaging streams in Norway.**

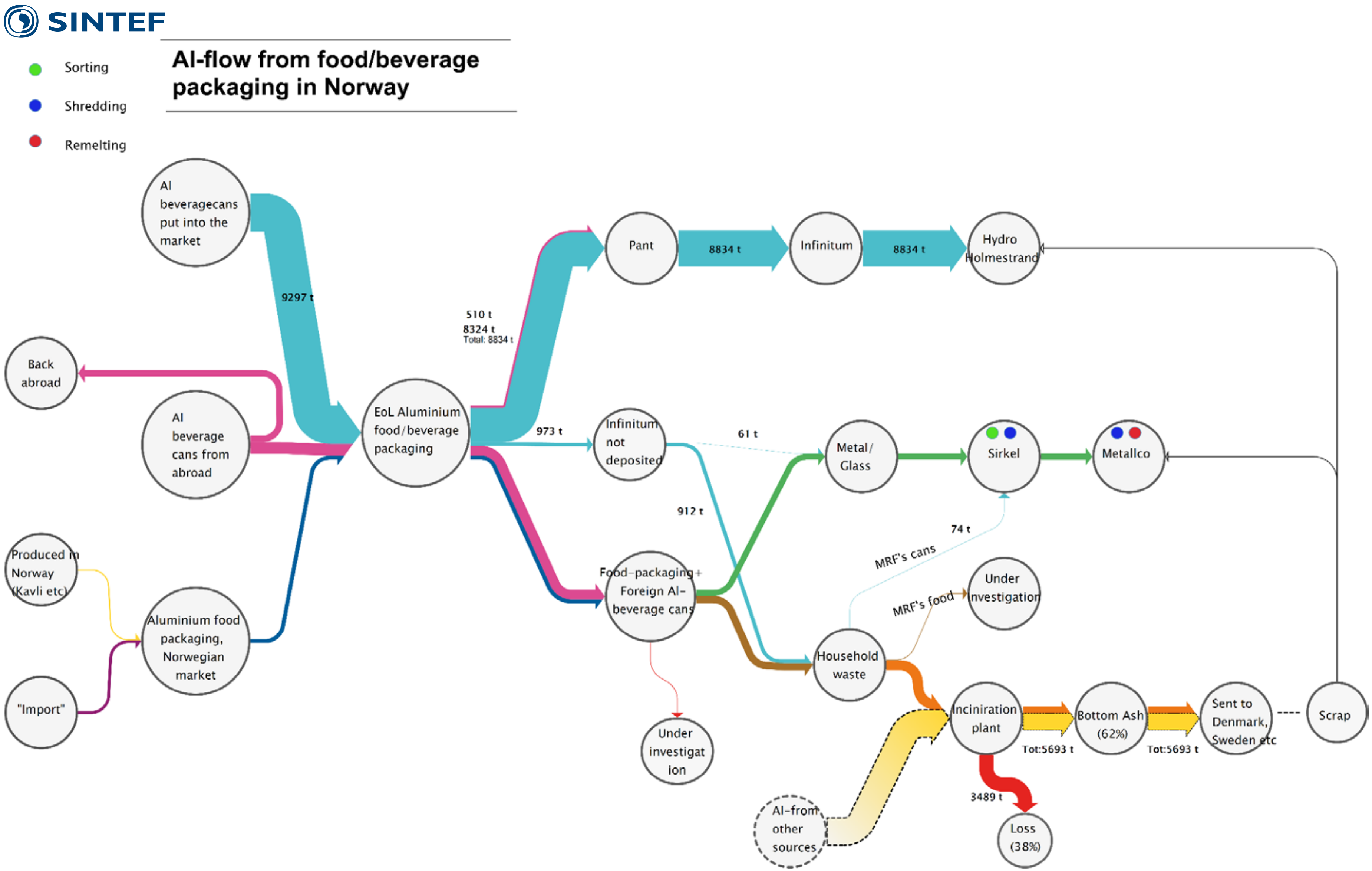


**Figure 4: Detailed Overview of Al-packaging streams. Note that the yellow arrow is not packaging but Al -from other sources going to incineration.**

### 2.5.3 Comments

From Figure 3 it is apparent that the aluminium flow of used beverage cans (UBC) dominates the market of used food and beverage packaging.

Most used beverage cans (UBC) are deposited in Infinium's machines. However, some UBC ends up in household waste and a lesser fraction in the municipal collection systems. Half of UBC purchased abroad is also deposited abroad. The other half is mostly entirely going to mmunicipal collection systems and incineration.

Figure 3 distinguishes between imported food and food produced and packed in Norway. Almost the same amount of food packaging ends up in Metal/Glass as in Household waste.

In Figure 4 Al from other sources that are incinerated (the yellow arrow) is included in Figure 3. The arrow is dashed to indicate that it is not packaging. It is however included to visualize the large amount of aluminium that ends up in incineration plants.

# 3 Quality and remelting

All aluminium products have certain specifications regarding properties that must be achieved. These properties could be strength, ductility, workability, electrical and thermal conductivity. Pure aluminium has high electrical conductivity, but cannot meet many of the other requirements, especially on mechanical properties, as pure aluminium is very soft. As a result of this, aluminium is "alloyed" which means that some amounts of other elements are added to achieve the preferred properties for that specific application.

To make a simple analogy; when making waffles you need milk, flour, sugar and eggs. More sugar makes them crisp: If you substitute salt for sugar, it gives the mix the same properties, but the finished product will probably be inedible. Mixing alloying elements into aluminium follows the same principles. The wrong alloying element will make the metal unsuitable for the intended purpose. And therefore, there is a wide variety of aluminium alloys, corresponding to the wide variety of applications.

The most common alloying elements are Si, Cu, Mn, Mg and Zn. These are used for different areas. Si is particular important in *cast alloys* to improve stiffness, flow properties as well as reducing shrinking problems during solidification. The other main class, *wrought alloys*, are given mechanical strength by work (e.g. rolling) or heat treatment after solidification.

The wide variety in alloying elements is, however, a disadvantage for recycling, as some elements are difficult/impossible to remove, and different methods must be used to separate the aluminium and alloying elements. This will be discussed further below.

## 3.1 Wrought and cast alloys

Of the two major classes of aluminium, wrought alloys and cast alloys, the former is generally of higher value regarding recycling than the latter. In general, the market for aluminium is increasing. However, the market for cast alloys is expected to decrease while the market for wrought alloys will most likely continue to increase. The fact that wrought alloys can be extruded, makes them very popular within the construction and the transportation sectors, as they can meet specifications that cast alloys simply cannot meet.

Most of the cast alloys produced are used in motor blocks. Each motor block is relatively large in metal volume, there is a large market, and the material property requirements are fairly low, which makes motor blocks ideal for cast alloys. Additionally, the shape is well suited for a casted product. However, because of the e-vehicle boom we are experiencing, this market is expected to decrease drastically as e-vehicles do not have motor blocks [5]. This could be a huge challenge as the demand for cast alloy aluminium would be too small compared to the supply of cast alloys.

On a technical level wrought alloys most critical properties are on mechanical properties. Accordingly, alloying elements are added to improve properties such as tensile strength, hardness, fracture toughness and ductility. The wrought aluminium is shaped by extrusion or rolling processes which by themselves may increase the strength of the material. These processes require the material to be plasticly deformed without failure. This requirement restricts the amount or type of alloying elements that can be present in the material. Too much and/or the wrong alloying elements could make the material unsuitable or impossible to extrude or roll. Consequently, the amount of alloying elements in wrought alloys are in general less than that of cast alloys.

Pure aluminium shrinks when it solidifies. This is a potential problem when casting. Most cast alloys include Si. Si has the unusual property that it expands when it solidifies, like water. Si is therefore added to counteract the shrinking of aluminium to get good casting properties. When Si-rich cast alloys are recycled together with wrought alloys the output will contain a high amount of Si, an unacceptable amount for wrought alloys. Finally, when recycling many different alloys together, the end result may contain unacceptable levels of many elements, even compared to the requirements for cast alloys.

Aluminium alloys are divided into alloy series where the number reveals the composition of the alloy. Moreover, each specific alloy has a composition limit meaning that the aluminium producer must follow alloy specifications when producing and distributing aluminium. For food packaging foil the most common alloys are 1XXX and 8XXX series, whereas for rigid container 3XXX and 5XXX are more common. The cast alloys usually have a 3-digit code. In Figure 5 below, the principal aluminium alloy system is illustrated.

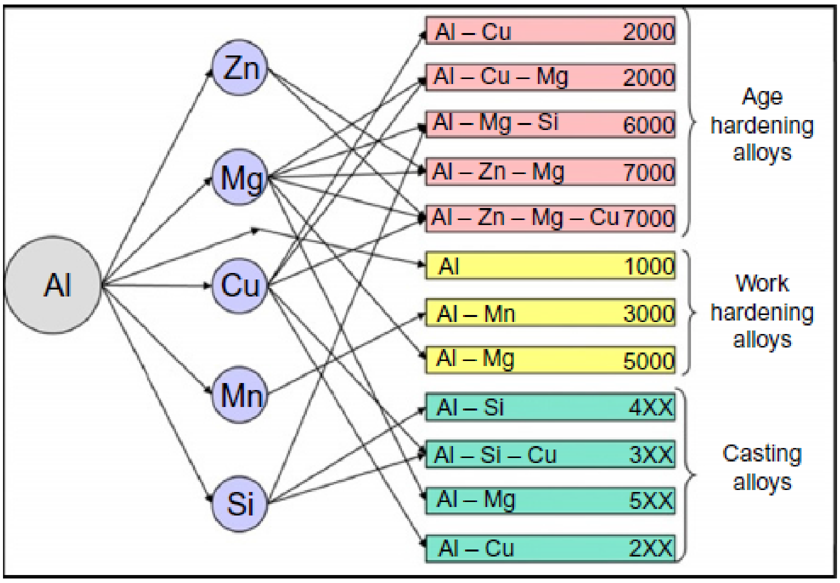


**Figure 5: Principal aluminium alloy systems. Figure from Tabereaux and Peterson. [6]**

### 3.1.1 Downgrading

The term downgrading usually refers to the loss in value excluding material loss when recycling aluminium scrap. This is also the way we use it in this report.

Aluminium is branded as a metal that can be recycled endlessly. However due to the composition of alloys and various impurities the quality of the metal is reduced for every re-melting process, the metal is down-graded/downcycled as illustrated in Figure 6. For loops where only one alloy is present, the wrought aluminium can be recycled again and again. However, when several alloys are present, and oxidation occur in the melting process, prime aluminium is added. Wrought aluminium is used for extrusion and rolling. The second loop represents cast aluminium. The input to cast aluminium is used aluminium with an amount of impurities and a mixture of alloy additives that prevent further extrusion or rolling. The “downcycling” from wrought alloys to cast alloys creates a kind of hierarchy with wrought alloys on top. This could be illustrated as a value chain with aluminium losing value as it moves down the hierarchy. An example of this downgrading could be a wrought alloy recycled resulting in it moving down to a cast alloy. After being recycled again it eventually gets “lost” by being used as a de-oxidation product in for instance steel, i.e. the Al metal is lost as metal as it is now an oxide.

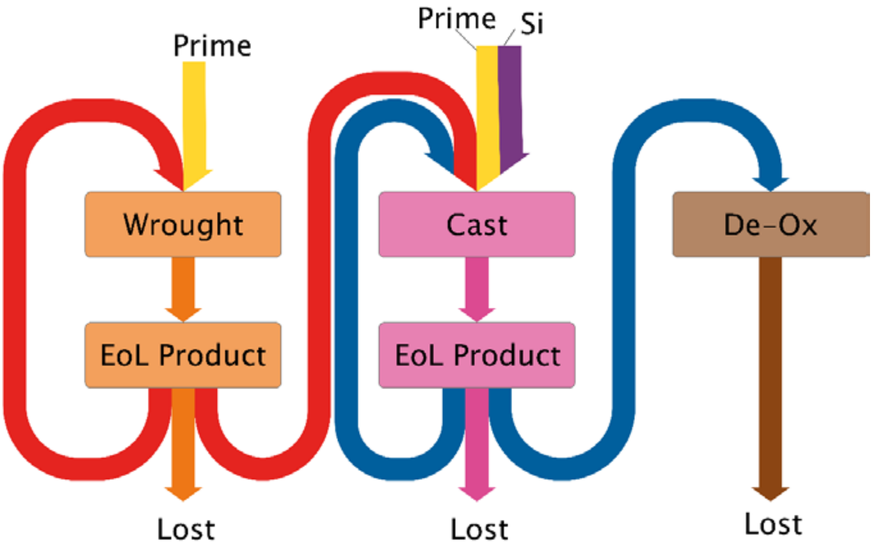


**Figure 6: Depiction of the downgrading occurring after each lifecycle. Figure inspired from Tabereaux and Peterson. [6]**

A Swedish article by Material Economics made a quantitative estimate of aluminium downgrading. They es-timated how much value gets lost after one lifecycle. The article estimates that as much as 62% of the value gets lost for every lifecycle, where 30% is due to material losses and 32% is due to the loss in value, known as downgrading [5].

## 3.2 Refining methods

A solution for recycling aluminium alloys containing to much alloying elements is to use refining methods. This could remove unwanted elements and impurities and could increase the value of the recycled aluminium. These methods could, to a certain degree, prevent downgrading. However, removal of unwanted alloying ele-ments is often difficult and very expensive as it requires additional (and often unknown) processes. As the alloying elements used are thermodynamically different, some are more difficult to remove than others. Dif-ferent processes are effective for removal of different alloying element which makes it even more complicated.

### 3.2.1 Methods for removing alloying elements

Figure 7 shows an overview of these methods and their effectiveness/difficulty for the different alloying elements. Removing unwanted elements from the aluminium melt can in many ways be compared to unmixing the waffle batter. It goes without saying that this is almost impossible, and it could be a simple analogy for why it would be very difficult to remove alloying elements and other unwanted elements from the aluminium melt.

It should also be noted that removal of parts of the unwanted elements could be considerably easier than removal of every trace of the unwanted element. As an example, there is 5% of an alloying element present in a melt. Removal of the element down to 1% could be relatively easy, but the last 1% could be very challenging and almost impossible in some cases.

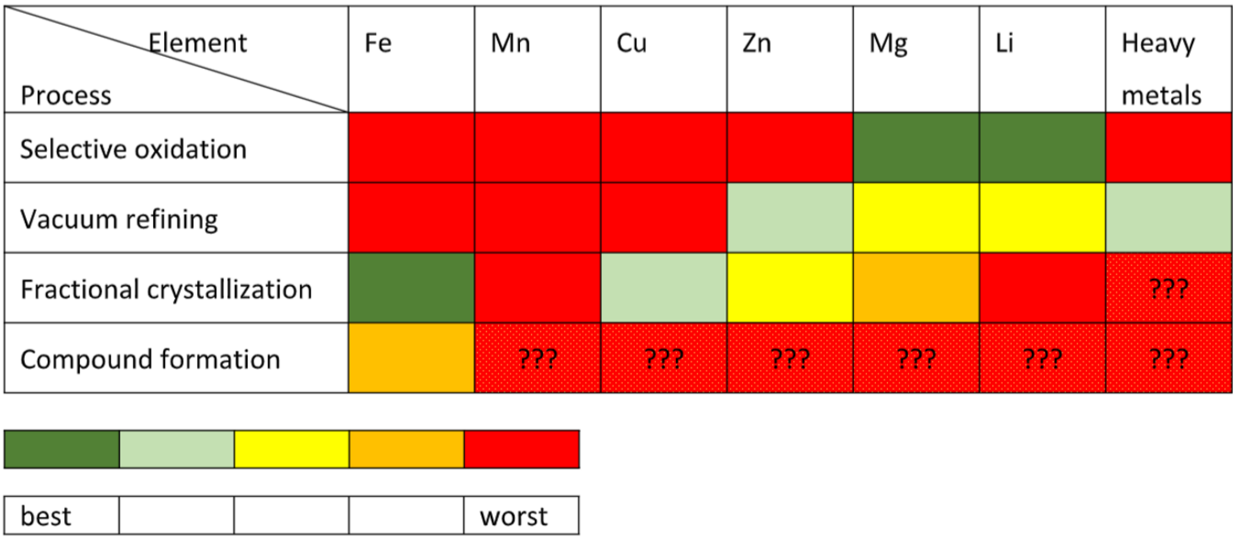


**Figure 7: Different refining methods for removing alloying elements in Aluminium. Figure taken from Chapter 10, Refining metals. [7]**

Figure 7 illustrates that, for instance, Mn is very difficult to remove. This implies that alloys with little to no Mn content in the specification can not be obtained from scrap containing Mn. This is the case for beverage can tops which is a 3xxx series. Even though some of the other alloying elements are easier to remove, similar challenges regarding specifications applies. Remelting several aluminium alloys together, could lead to an end mixture that fit no specifications. Hence it is very challenging to design and produce a product from scrap metal only. It should be noted that Si, which is high in cast alloys, is not included in the table. However there exist technically proven refining processes for Si, such as fractional crystallization.

### 3.2.2 Dilution

Dilution is not, strictly speaking, a refining method. However the scrap mixture often does not meet the requirements of either wrought or cast alloys. As a result, the scrap is usually diluted with pure aluminium to meet the wanted alloy specifications. It is, in general, at present much cheaper to dilute a mixture with pure aluminium than to remove unwanted elements. If one wants to refine the molten scrap, one needs to add one or more new processing steps, which could potentially cost a lot of money and make the total process unprofitable. It seems like the saying "dilution is the solution" is still valid in today's industry.

A consequence of dilution with pure aluminium is the need to add more additives after dilution. For example, the remelted scrap contains the wanted amount of 2% Mn. But, due to other unwanted elements the mixture was diluted with 50% pure Al, consequently the mixture only contains 1% Mn after dilution. As a result, more Mn must be added after dilution.

Mg is a common alloying element that is used in significant amounts in 5XXX alloys. For an Mg rich alloy a considerable amount of Mg is lost if oxidation occurs in the recycling process. The output of Mg is therefore often much smaller than the input, and for Mg rich alloys adding more Mg is often necessary. On the positive side, the removal of unwanted Mg is relatively easy compared to other alloying elements as is also seen in Figure 7.

## 3.3 Other quality aspects than chemistry

Impurities and particles/inclusions are also important variables that will reduce the quality of the recycled aluminium. For instance a particle in the size range of the gauge thickness would lead to a hole in the beverage can and food container. This typically only happens 1 out of a million times, due to good refining such as filtration and gas purging by the manufacturers. The impurities can origin from organic compounds, oxides, carbides etc, but will not be discussed further in this report.

## 3.4 Used beverage cans (UBC) remelting in general.

The aluminium beverage can is one of the most popular (best known, most widespread) aluminium product innovations of all time. Worldwide it is produced over 250 million cans every year, and they account for about 20% of the total consumption of aluminium [7]. Even though UBC's are easier to recycle compared to food packaging, there are still challenges when recycling. In Norway the system implemented for UBC's is often considered a closed loop system, but the reality is more complicated. The aluminium beverage cans as we know them today, are made from three pieces, the body, the lid and the ring. The three pieces are made from different alloys to meet different requirements. The body must be mechanically strong enough and as thin as possible. The ring has to "snap" when opening the can lid, which required a more brittle alloy. The bodies are made by rolling wrought aluminium ingots into thin Al-sheets. The most common alloys today are Mn-based like AA3004 or AA3104. Two Al-alloys containing Mg was developed for the lid, and often AA5182 is used. The fact that the Al-beverage can consists of three alloys makes the closed loop more difficult. In a typical 330 ml UBC, the mass of the top is 2.4 g and body 10.4 g.

When remelting the UBCs one ends up with an alloy with composition too high in Mg for the body and too high in Mn for the lid. To close the loop dilution or additives is used. The composition in % of the different alloys and for the typical composition of remelted UBCs can be seen in Table 1.

**Table 1: Alloys typically used in Al-beverage cans and the composition of UBC scrap [7]. The can body is made either of AA 3004 or AA 3104**

| use (alloy) | %Mg | %Mn | %Cu | %Fe | %Si |
|---|---|---|---|---|---|
| **can body (AA 3004)** | 0.8 – 1.3 | 1.0 – 1.5 | <0.25 | <0.7 | <0.3 |
| **can body (AA 3104)** | 0.8 – 1.4 | 0.8 – 1.3 | <0.25 | <0.8 | <0.4 |
| **can top (AA 5182)** | 4.0 – 5.0 | 0.2 – 0.5 | <0.15 | <0.35 | <0.2 |
| **typical remelted UBC** | 1.95 | 0.9 | | | |

## 3.5 Food packaging remelting at Metallco

Above is the *general* problem of remelting beverage cans, consisting of different alloys, outlined. Here the specific case of remelting food packaging collected in Norway at Metallco is investigated.

Metallco started remelting food containers collected in metal/glass containers in 2020. (See Figure 3 for over-view). The procedures for operating their new rotary furnace are still under development. When this report is written a total of seven batches, each of about 3 tons has been remelted. The composition of each of these batches are measured. Metallco aims to produce alloy AC 46000 which is very similar to the more known AA380. The average and standard deviation of the composition of the seven batches, and the limits with min and max to give AC 46000 are given in Table 2. The silicon content was generally low, and for most of the analyses showed up as < 0.8 %.

**Table 2: The average and standard deviation (in %) in chemical composition of the seven batches of food cans melted at Metallco together with the chemical specification limit for AC46000 alloy.**

| Element | Average | Stdev | Min | Max |
|---|---|---|---|---|
| Fe | 0.73 | 0.11 | 0.7 | 1.10 |
| Cu | 1.51 | 0.24 | 2 | 3.50 |
| Mn | 0.549 | 0.052 | 0.1 | 0.55 |
| Mg | 0.026 | 0.031 | 0.1 | 0.55 |
| Cr | 0.043 | 0.018 | | 0.15 |
| Ni | 0.048 | 0.015 | | 0.55 |
| Zn | 2.17 | 0.44 | | 1.20 |
| Pb | 0.16 | 0.15 | | 0.35 |
| Sn | 0.44 | 0.14 | | 0.10 |

From Table 2 it can be seen that remelting food cans gave abnormally high contents of tin (Sn). The origin of Sn in the melt is unknown. One proposed source is Fe that didn't get sorted out through magnetic separation. Fe cans can often contain Sn or be Sn-plated. However, calculations show that Fe in cans could not contribute to the high Sn because this would require a substantial amount of iron to be present in the separated scrap. Other proposed sources are coating/paint on the packaging or the presence of pure tin packaging in the incoming scrap.

Tin should not exceed 0.10% as higher levels give brittle goods. The high and varying tin content means that metal cannot transfer directly to the melting furnace but must be melted twice.

Given these measurements Sn stood out as the toughest challenge as the content was much higher than the composition limit for the alloy. Given no known method of removing Sn a lot of dilution is needed. The amount needed given the average measurements can be seen in Figure 8. The second to worst element was Zn which also was above the limit. The amount of dilution needed excluding the Sn content can be seen in Figure 9.

From Table 2 it is seen that no other elements need dilution. Adding alloying elements such as Si would obviously still be needed.

### 3.5.1 Sankey diagrams of needed dilution

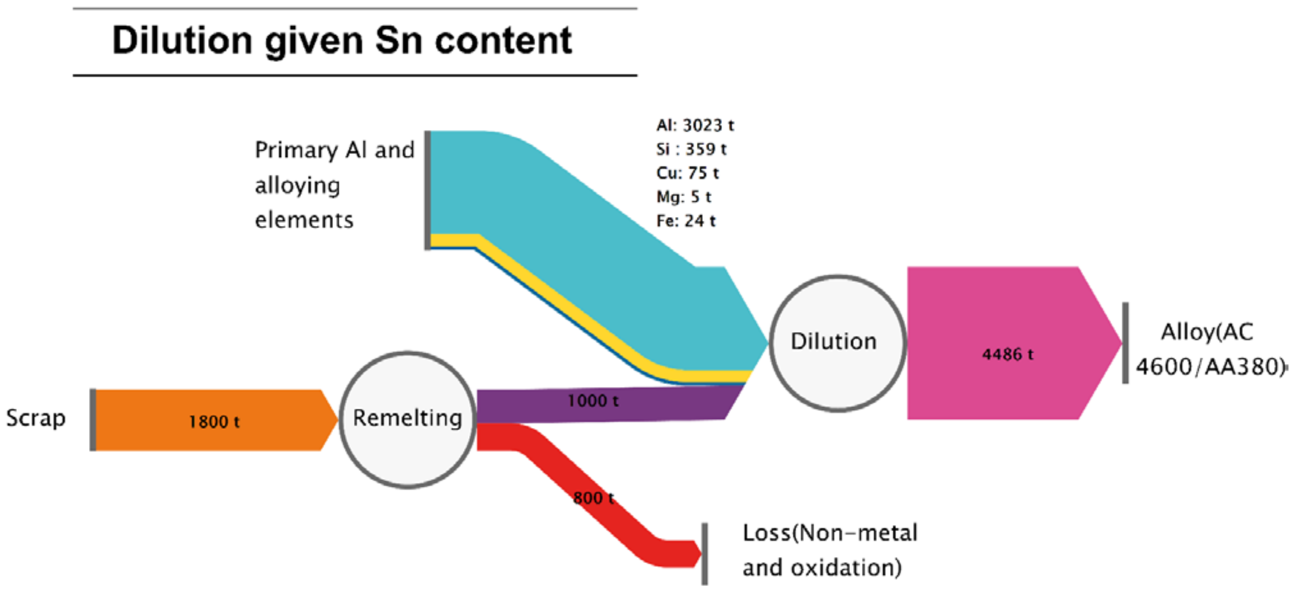


**Figure 8: Dilution needed for given Sn-content. Adjusted for 1000 t scrap. Calculated based on 1000t scrap set as reference.**

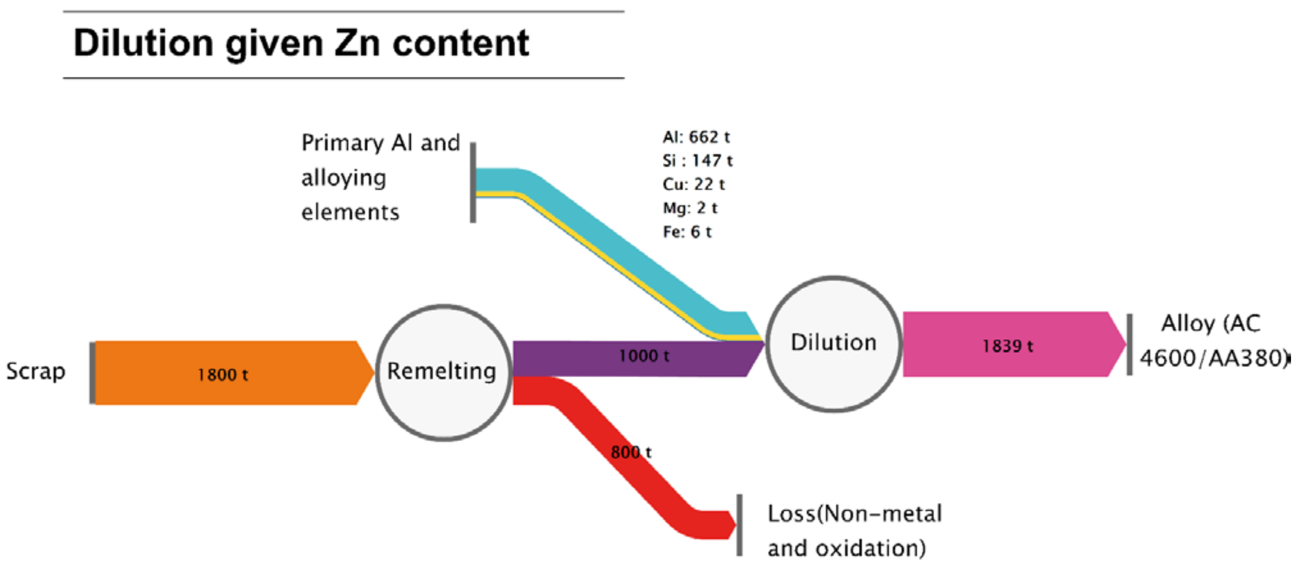


**Figure 9: Dilution needed for given Zn-content (Excluding Sn). Calculated based on 1000t scrap set as reference.**

## 3.6 Heavy Metals

Heavy metals have historically been a significant challenge in bottom ash recycling as elements such as lead (Pb) and mercury (Hg) are present. Both are highly toxic. Additionally, from a metallurgical perspective Hg is not used in any alloy which makes it unwanted. (They are banned in products.) Fortunately, the amount of heavy metals in scrap seems to decline considerably due to restrictions on these elements.

# 4 Infrastructures in Scandinavia

In Norway, as in many other countries, the infrastructure designed to support recycling has received increased attention in recent years. Several different proposed measures to improve recycling are already implemented or are planned to be carried out. As improving recycling involve many areas, the measures taken are within better technology, new plants, new tools, or better facilitation for recycling. A few of the measures taken or planned in Norway will be discussed briefly in this section.

## 4.1 Regulations for food and beverage packaging in Norway

Extended Producer Responsibility (EPR) is a policy approach which gives the producer or importer responsibility for treatment of post-consumer products. Such a system is operated in Norway. Waste guidelines state the all importers and producers who place more than 1000 kg of packaging on the market in that given year must be a member of such an EPR-system. A fee is paid to the EPR company based on the amount of packaging placed on the market. The total fees paid by the member companies partly fund the collection and treatment of end of post-consumer packaging products. This approach applies to all types of food packaging materials including aluminium packaging.

However, beverage packaging has its own fees and regulation system. The beverage can fees are divided in two parts, basic tax (grunnavgift) and environmental tax (miljøavgift). These fees for 2020 are shown in Table 3. In accordance with legislation, the environmental tax is reduced linearly with higher collection rates and the tax disappears when the collection rate exceeds 95%.

**Table 3: Beverage packaging tax rates in Norway in 2020. [8]**

| **Environmental tax rate** | |
|---|---|
| Glass and metal | NOK 5.99 per unit |
| Plastic | NOK 3.62 per unit |
| Cardboard | NOK 1.48 per unit |
| **Basic tax** | |
| Basic tax on single use packaging | NOK 1.23 per unit |

Infinitum runs the deposit-refund system for aluminium beverage cans and PET-bottles in Norway. For a packaging user to be part of the deposit-refund system (panteordningen) run by Infinitum it must be a member, paying a one-time fee of 10 000 NOK. In addition, the members pay a per unit fee (EPR-cost) which is paid directly to Infinitum by the beverage producers. This comes in addition to the tax, but it is in general much smaller than the environmental tax, which producers effectively avoid by joining the deposit-refund system. In 2020 the EPR-cost for aluminium was negative, -0.08 NOK. The EPR-cost for the different materials is presented in Table 4. Aluminium is the only packaging material producers get refunded for using. As Table 4 shows, producers using steel or plastic have to pay.

**Table 4: EPR costs as of 2020 to be paid to Infinitum. (Source: Infinitum.no)**

| Metal | NOK |
|---|---|
| Basic EPR cost aluminium | - 0.08 |
| Basic EPR cost steel | 0.21 |
| Surcharge for label or sleeve covering 75% or more of the packaging | 0.03 |
| Surcharge for standard bar code, sold both in- and outside Norway | 0.06 |
| | |
| Plastic | |
| Basic EPR cost PET | 0.10 |
| Basic EPR cost HDPE | 0.10 |
| Surcharge light blue transparent | 0.08 |
| Surcharge other colour, or coloured sleeve covering 75% or more of the packaging | 0.15 |
| Surcharge for standard bar code, sold both in- and outside Norway | 0.06 |
| | |

## 4.2 Changes in legislation of recycling points

The packaging legislations in Europe are closely linked to the measurement of recycling and energy recovery of packaging materials. The various countries and markets have specific goals for annual recycling rates based on measurements. The European Union have recently (2019) changed the rules of how to measure recycled scrap with a new point of measurement which will also be the guideline for Norway [9]. Until recently the waste that leaves the sorting facility has been measured (red dashed line number 1 in Figure 10), now, the materials that enters the recycling process should be measured (red dashed line number 2 in Figure 10). As a result the measurements are more accurate and will not include food residue etc which previously could have made the recycling rates look better than what they actually were. [9] [10]

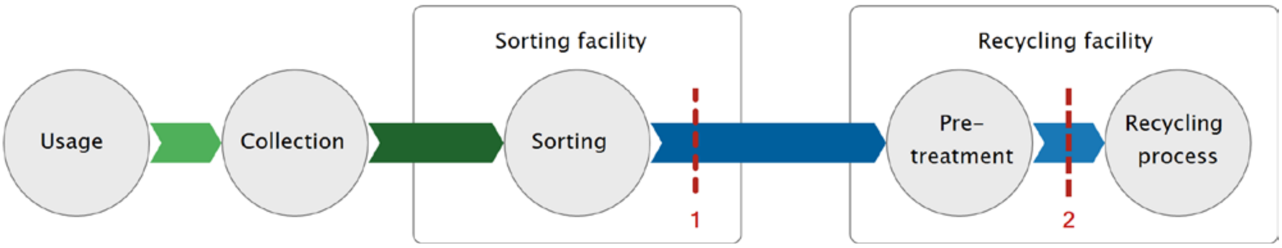


**Figure 10:New point of measurement for recycling that the EU changed recently (2019) [9] [10].**

## 4.3 New labelling for sorting

Better sorting is one of the core topics in discussions about improvement of recycling in general. This certainly also applies for aluminium. Actions in sorting can involve sorting technology and/or better systems that helps improved sorting by the consumer. The change in waste labelling introduced in Norway in 2020 is an example of the latter. The updated labelling were developed by Avfall Norge and LOOP [11] and are meant to make it easier for the consumer to recycle efficiently. The symbols illustrate typical products in the fraction and the colour coding will simplify sorting into different waste groups. Metals have a grey background. The symbol for packaging is a can, whereas metals in general is depicted by a frying pan as seen in Figure 11 which gives an overview of more labels. For more information see [11].

**Figure 11: New labelling being introduced in Norway.**

## 4.4 Updated reward/fee for deposit

The impact of the size of the reward/deposit (pant) on the collection rate can be studied as it has been increased for the first time since 1993. The reward/depositum for depositing/delivering beverage cans/bottles was increased from 1 NOK to 2 NOK for small beverage containers (< 0.5 l) and from 2.5 NOK to 3 NOK for large beverage containers (> 0.5 l). This was decided by the Norwegian government through the Ministry of Climate and Environment. The change was done gradually over a nine-month period in 2018 to allow stores and warehouses to adjust. From 2017 to 2019 collection of aluminium beverage cans through "reverse" deposit machines increased from 84.3% to 89.5% [12] [13]. This indicates that a higher reward had an overall positive effect, assuming that other conditions that could affect this collection remained more or less the same.

## 4.5 Trends regarding sorting of municipal waste

MRFs (Material recovery facilities) are huge recycling plants designed to handle every fraction in municipal waste. Compared to a "traditional" incineration plant, an MRF is sorting the household waste into different streams instead of burning it right away. This would hopefully extract more value from the waste and keep more resources in the economy. In Norway as of July 2020, there are two MRF plants. One is located outside the city of Stavanger. This plant is called IVAR and is the result of the cooperation of eight counties[1]. It started operations in 2018. The second plant is named ROAF and is located outside of Oslo. ROAF was opened in 2014[2]. A third, similar plant is planned outside of Trondheim, called SESAM.

One of the main criticisms against MRF's is the cost of building and running these plants. The value gained in yield and quality of the materials from this plant should hopefully be bigger than the cost of building and running the plant itself.

The main advantage of these types of sorting plants is that one doesn't have to rely on the consumer's ability and motivation to sort the household waste. There have been many attempts to make consumers sort the household waste into separate bins (e.g. advertising in media). It is debatable whether these incentives are entirely successful. What this discussion is really about is if the consumers' sorting of waste is good enough. MRFs remove this consumer dependence as it sorts the waste by technological solutions. Whether the technological

[1] https://www.ivar.no/ettersorteringsanlegg/
[2] https://www.roaf.no/om-roaf/roaf-historie/

solutions are better than the consumers in sorting is a difficult question and will not be discussed in this report. As these plants in Norway are relatively new, it may get clearer in the next few years as to what is the best solution. The best solution is dependent on several factors, among others cost, energy usage, water usage and incentives.

## 4.6 Trends in Sweden and Denmark

The waste industry in Norway is seemingly highly connected to both Sweden and Denmark. By learning from each other one could more easily find the most effective solutions and potentially eliminate measures that turned out to be sub-optimal.

Sweden:

- Less than one percent of municipal waste goes to landfill in Sweden [14]
- A significant portion of the Norwegian municipal waste is sent to Sweden for incineration
- Sweden also introduced an incineration fee as of April 2020. [15]

Denmark:

- A political agreement was reached in Denmark in 2020 that should secure a sustainable and environmental waste sector within 2030.

## 4.7 Remelting food cans started in Norway 2020

The aluminium food packaging scrap organised by Norsk Metallgjenvinning had earlier been bought by Metallco in Oslo and then sold abroad. From a circular (registration) perspective it is a problem when one does not know what happens with this material afterwards. It can be unknown if the scrap is being recycled, reused, incinerated, or simply sent to landfill. However, as mentioned previously, Metallco decided to test remelt food packaging themselves as of 2020. As remelting includes a lot of challenges, one could hope/assume that a significant amount of knowledge will be gained about the remelting processes of scrap, which would benefit recycling in Norway in general and could benefit other countries as well. In general, economy of scale can be a counterargument to regional recycling solutions.

# 5 Discussion and Conclusion

The purpose of this report was to give an overview of Al-packaging streams in Norway, and metal quality when recycling Al.

Most effort was given to obtaining a good overview over the aluminium's packaging flows and convert this into useful Sankey diagrams. The overview shows that the deposit systems collect most of the used beverage cans. An interesting aspect is the substantial amount of foreign beverage cans that are introduced into the Norwegian market. One could make a qualified guess that a lot of these cans comes from Sweden and the amount that goes back out of Norway could be the amount Norwegians bring back into Sweden to deposit there.

The glass/metal collections system on the other hand, collects only half of the metal products put on the market. The other half goes into the household waste. The considerable tonnage of aluminium not originating from packaging, that goes into household waste is surprising.

## 5.1 Incineration vs. sorting

Regarding metal quality the remelting of scrap is challenging as the streams are not as homogeneous and pure as one prefers. The big question of incineration of scrap vs sorting was not answered as this is a very difficult question that people disagree on depending on where they are in the value chain.

Previous studies have concluded that one wants to avoid incineration as much as possible as this process results in loss of material resources. In general, processes where a higher yield of the materials can be obtained are preferred. There are, however, pros and cons with both strategies as they stand today. Cleaning and sorting of used packaging consume energy and possible organic remains leads to operational problems in the remelting process. Incineration on the other hand, leads to more losses as already pointed out.

## 5.2 Packaging vs other Al-scrap (thickness)

Aluminium packaging is, in many ways different, from other types of aluminium scrap. The most significant differences are that it consists of smaller units, it is generally thinner, and it often includes/consist of a significant amount of organic leftovers. All these characteristics make the packaging difficult to recycle.

Al-packaging are in general quite small and thin which makes them more prone to oxidation when being put through the recycling processes. This will affect the total yield of the recycling process, as the oxidized Al is lost. Alloying elements, such as magnesium, could also be oxidized and thereby lost. One way to minimize oxidation is to press the scrap into high density blocks before remelting. Another is adding the scrap into a metal bath with vortex. Here the scrap will be trapped underneath the (molten) metal surface so fast that it does not have time to oxidise.

Another challenge is the organics remnants. Firstly, the organic remnants will make the remelting process unstable and may produce noxious fumes. Burning of the organics before remelting, (decoating), is therefore a solution. Pre-heating contaminated aluminium scrap gives an overall positive effect on yield and quality. Another solution to organic remnants is that used Al-packaging is melted in a rotary furnace together with salt for protection. The organic content allowed in salt processes is usually less than 10% whereas for non-salt processes less than 3% organics is a necessity.

Beverage cans are easier to recycle than food packaging because they are more homogeneous (in alloy, gauge thickness, coating) but also include fewer organic remnants. The liquid is evaporating, and leftovers are generally easier to remove by the consumer. Food packaging require a much higher effort to achieve the same level of cleanliness. Thus, food packaging will contain a substantial amount of organics remnants which makes the recycling process more challenging. In this report the problem of mixing is also demonstrated. Finding the Sn-source and eliminating this, or figuring out ways to minimize Sn and Zn, is therefore of high importance for the future food packaging in Norway.

Al-packaging scrap from bottom ash can also be too high on Zn and Mn, but have less organics as this has been burnt off during incineration. This incineration step can be compared with decoating, the difference is the better control over the process in specialised decoating units for aluminium. The problem of too high alloying content can be solved by sorting the bottom ash after alloying content.

Despite all these recycling challenges, there will always be a steady stream of Al- scrap originating from packaging due to its popularity and the short lifetime of packaging products. Therefore, it will be of high importance to find the optimal recycling routes for used aluminium packaging.

## 5.3 Circular economy

The concept of the circular economy suggests changing from a linear economy, where resources are extracted from the environment—fabricated, used once and disposed--to one where materials circulate in a closed loop. Numerous definitions and interpretations of the concept Circular Economy can be found in the literature.

Reuse of materials is not a new nor unique thought. Recycling has always taken place for valuable materials such as gold, and aluminium. In this report we have described the circularity of aluminium packaging and challenges at the micro level (products, companies, consumers), and macro level (city, region, nation and beyond).

The idea of recycling everything with 100 % recovery, and without any downgrading, is like the dream of the Perpetuum mobile. This kind of machine is impossible, as it would violate the second law of thermodynamics. The same applies for recycling processes. Recycling without losses is not possible, but to continually improve the processes is usually within reach.

## 5.4 Future work

There are several other interesting subjects that can be investigated further. A list of these includes:

1. Look closer at sorting vs incineration from a metal quality view and an economic view.
2. See the effect of the new labelling for sorting that is introduced.
3. Investigate the possibility of a recycled wrought alloy and what is needed to accomplish this.
4. Look at the infrastructure of the different streams and possible improvements.
5. Look at if MRF's turned out to be a good investment

The case study revealed that regarding the remelting of scrap tin was very problematic. Further investigating of its source, and how to possibly solve it could be very interesting. This could be done in cooperation with Metallco and one could observe this situation over time.

## 5.5 Conclusion

This report:

- Presents the Al flows of packaging in Norway in Sankey diagrams
- Points out the need for dilution to meet alloy specifications for food packaging
- Demonstrates how well the beverage cans systems works

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