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Report

Collection of aluminium packaging today

A literature study on collection systems for aluminium packaging particularly in China, the United States and the European Union.

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ABSTRACT

This report investigates the collection of aluminium packaging, particularly in China, the United States and the European Union. A literature search among journal articles using Google Scholar, company and organization reports and newspapers was conducted. As recycling of aluminium requires only 5% of the energy needed to produce primary aluminium, it is desirable to recycle as much aluminium as possible. The article presents the main characteristics of the collection systems in the three regions and how it is influenced by consumer behaviour, processing requirements, economy and policies. Convenience and money were identified to have the largest influence on consumers' willingness to recycle. Source separation conducted by the consumer was found to have a positive influence on the possible recycling rate with today's processing technology. Different ways of source separation and how they influence collection rate and processing requirements were discussed. No single best-practice system for collection of aluminium packaging was found, but key factors influencing the collection system and aluminium recycling rates was identified and discussed.

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1 Introduction

Aluminium is a lightweight metal with vast applications, ranging from airplanes and buildings to beverage cans. Aluminium is classified as a permanent material, which means that in theory, aluminium scrap can be recycled infinitely without losing its properties. The energy required to recycle aluminium is only about 5% of the energy required to make virgin aluminium from bauxite. Therefore, effective recycling of aluminium has the potential of creating a more sustainable environment, as well as supporting the transition from a linear to a circular economy.

This report will provide an overview of the aluminium packaging recycling situation in China, United States and the European Union. As Al packaging is often collected with other types of waste, some perspectives and examples regarding recycling in general are also considered.

1.1 Method and limitations

This literature study is mainly based on journal articles from literature search using Google Scholar, websites and reports from associations, organizations and authorities. Some newspaper articles have also been included. As the background literature is only from open sources and libraries accessible with an NTNU student account, no internal or confidential reports have been considered. Data concerning performance of private stakeholders in the recycling industry is thus limited. Some articles in Chinese was translated and included in this report as well.

1.2 Scope

A vast number of factors can be regarded as influential on the recycling of aluminium packaging. This report will consider the route from an end-of-life product to recycled aluminium ready for fabrication into a new product (Figure 1), and the influence of policy and economy on these steps.

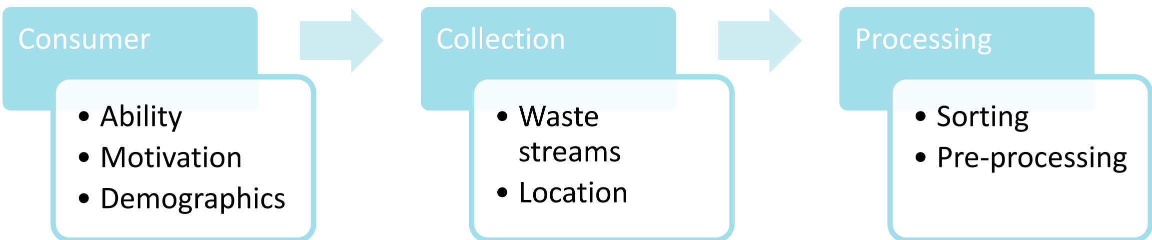

Figure 1: Visualization of the scope of the report

How Al packaging is collected can both influence consumer behaviour and requirements for processing. Therefore, the design of the collection system is essential in increasing aluminium recycling. As there are many practices on how to do this, different collection methods will be investigated. The consumers primarily decide whether they want to recycle, and secondary how they do it. Factors that influence the consumers' recycling behaviours are investigated. Processing includes automated sorting which has a large influence on the quality and amount of scrap entering the re-melting step. Factors that will be discussed in some degree includes product design in terms of alloying and composite materials, but excludes efforts conducted to increase consumers' knowledge about recycling and the quality of waste source separated by the consumer. The latter would have been interesting to look at, especially in terms of seeing how different collection methods influences the quality of the collected waste, but little information on the subject was possible to obtain.

1.3 Definitions and abbreviations

Al (Aluminium) – chemical symbol for aluminium

CO2e (Carbon dioxide equivalent) – common unit used to measure emissions of greenhouse gases

Curbside collection – waste is collected from bins on the side of the road near the residence.

Drop-off recycling – residents bring their recyclables to a drop-off point away from their residence.

EPR (Extended producer responsibility) – Policy where the producer is responsible for the collection and treatment of their products when they reach their end-of-life

EoL (end-of-life) – A product that has reached the end of its useful life

GHG (Greenhouse gas) – Any gas that contribute to the greenhouse effect in the earth's atmosphere.

MRF (Material recovery facility) – Facility where waste streams are separated and prepared before they are sold to end-use manufacturers

MSW (Municipal solid waste) – Waste generated on a daily basis in households, and similar waste from other sources.

New scrap/pre-consumer scrap – scrap created in the manufacturing process

Old scrap/post-consumer scrap – scrap created after a product has reached its end-of-life

PAYT (Pay as you throw) – Residents must pay a fee depending on the amount of (residual) waste they leave for collection. The fee can be based on volume, number of units (bags), collection frequency or weight. Sorted recyclables are often free of charge, creating an incentive to source separate.

Primary aluminium – Aluminium produced from bauxite ore

Secondary aluminium – Aluminium produced from scrap.

2 General and worldwide characteristics

2.1 Aluminium packaging

Aluminium is widely used to preserve food due to its barrier against oxygen and light. The beverage can is the most widespread example. Foils, aerosol cans, trays and squeezable tubes are also common examples (Figure 2). Aluminium is also used in multi-material packaging, often as a protective coating on either plastic, paper or carton. The Al content of such composite materials is often low, typically around 20% in plastic bags and 4% in beverage cartons [1].

Figure 2: Typical examples of household Al packaging

2.2 Recovery methods

Generally, there are two ways of recovering recyclable Al from MSW, namely extraction from incinerator bottom ash and source separating and processing Al from waste. Source separation can be done automatically with an eddy current separator, or manually either by the consumer before disposing the Al waste or by manual labour at MRFs. Often, a combination of central sorting and sorting by the consumer is applied. Typically, the consumer is expected to source separate some recyclables, and then these recyclables are sorted material-wise in MRFs after collection. Incineration is an emerging method for avoiding landfilling of residual waste, and often involves energy recovery. When incinerated, the aluminium will melt and react with oxygen. Oxidised aluminium is not desirable and is regarded as loss. The oxidation rates depends on the thickness and alloy of the aluminium, ranging from under 10% for rigid packaging such as beverage cans to more than 50% for flexible packaging such as aluminium foil [2].

The general methods for collection are listed below

- **Curbside collection** – waste is collected from a bin near the residence. Normally, a single-family residence has a private bin, while multi-family residences like apartment blocks share a common bin. The number of separate waste streams collected at the curb varies, but residual waste is generally always collected. Some or all recyclables can be collected at the curbside, either all together in single-streams or source separated in multiple streams.
- **Drop-off points** – collection points often located further away from residences where citizens must bring their recyclables and sort them in the correct bin.
- **Recycling centres** – large facilities which often accept other waste in addition to household waste, such as furniture and hazardous waste. Often a lot rarer than drop-off points with regard to the number of facilities per inhabitant.
- **Deposit-return scheme** – a deposit is paid when buying an item and returned as the item is returned. For packaging, this is common for beverage containers. The return system often relies on reverse vending machines to register the containers delivered and return the deposit.
- **Informal collection** – recyclables are sold to a person who works in the informal waste collection system, usually by door-to-door service. Typically, only items that can be sold for a revenue is accepted.
- **Producer take-back** – producers organize collection and treatment of their own products when they reach EoL.

Sometimes it is hard to differentiate between curbside and drop-off. Curbside collection in city areas are often shared between many households, just like drop-off points, and drop-off point can be placed very near the residence, just like curbside recycling.

2.3 Recyclability

Aluminium is in theory an easy and effective material to recycle. In principle, pure aluminium scrap can be turned into ingots with the same quality as virgin aluminium simply by re-melting it in a furnace. However, the introduction of alloying and impurity elements, as well as coatings and contamination from food remains and other waste sources complicates the recycling of aluminium packaging.

In aluminium cans, the lid and the body are produced from two different alloys with different requirements for concentrations of magnesium and manganese. They also have different maximum acceptable values of impurity elements such as iron, copper and silicon. A study that investigated the quality of aluminium recycled over 30 cycles, found that the required purity for can bodies could only be achieved when beverage cans was recycled in a closed loop (i.e. from beverage can to beverage can). Mixed aluminium scrap had too high levels of impurities when recycled over many cycles. Separation of the lid and the body was also investigated, and found to be the only way to make closed-loop recycling possible without adding manganese in the recycling process [3]. It is likely that this is applicable to other aluminium products as well, indicating that separation of packaging waste in terms of alloys will lower the climate change impacts of aluminium packaging. As pointed out by [4], it is impossible to reach perfect recycling (no loss, perfect ability to replace virgin material). The consequence is that, after a certain time, disposal or loss to the environment of any EoL material is inevitable. As recycled aluminium has a good ability to replace virgin material, it has the potential of being recycled many times before is degrades, given that the losses in the recycling process is low.

2.3.1 Mixed material packaging

Some food packaging consists of several different packaging materials to provide the required properties such as oxygen and light barrier, flexibility and visual appearance. A widely used example are metalized plastic bags often containing chips and other snacks. Separating the plastic from the aluminium is challenging, and no commercial recycling facilities are able to do this efficiently today. Therefore, most of these bags go to either landfill or incineration. Because the aluminium layer on such bags is extremely thin, recovery of aluminium from bottom ashes in incinerators are unlikely in this case.

Several experiments which aims to separate aluminium from metalized plastic films have been conducted. This often involves chemical treatment, either to dissolve one of the two materials in the multilayer film, or by weakening the adhesive forces between the layers [1]. Many of these methods have challenges that might prevent upscaling to industrial processes, such as low reaction rates, complicated recovery of dissolved aluminium and extensive use of expensive and/or harmful chemicals.

2.4 Global production and demand

Aluminium is in high demand all over the world, and the global production of aluminium is increasing, mainly due to the increased demand in developing countries. Most of the recent increase in production (Figure 3a) is accounted for by China. As seen in Figure 3b and Figure 4, packaging accounts for a small portion of the in-use aluminium stock, but a large portion of the demand and discard. This is because of the short lifetime of packaging products, which can reach their EoL many times each year. Because of this, aluminium packaging produces a predictable and continuous stream of Al scrap. The aluminium demand of the packaging sector is about the same as the discard. This means that it is theoretically possible to supply nearly all Al needed for packaging from recycled Al packaging, given no loss or downcycling. To compare, aluminium in cars reach EoL after around 15 years, while aluminium in buildings can stay in-stock for 100 years or more.

Both the demand for aluminium, the generation of MSW and the percentage of MSW consisting of packaging has historically increased as a country has expanded its economy. Therefore, we can expect the demand for primary aluminium worldwide to continue to increase as more countries become industrialized.

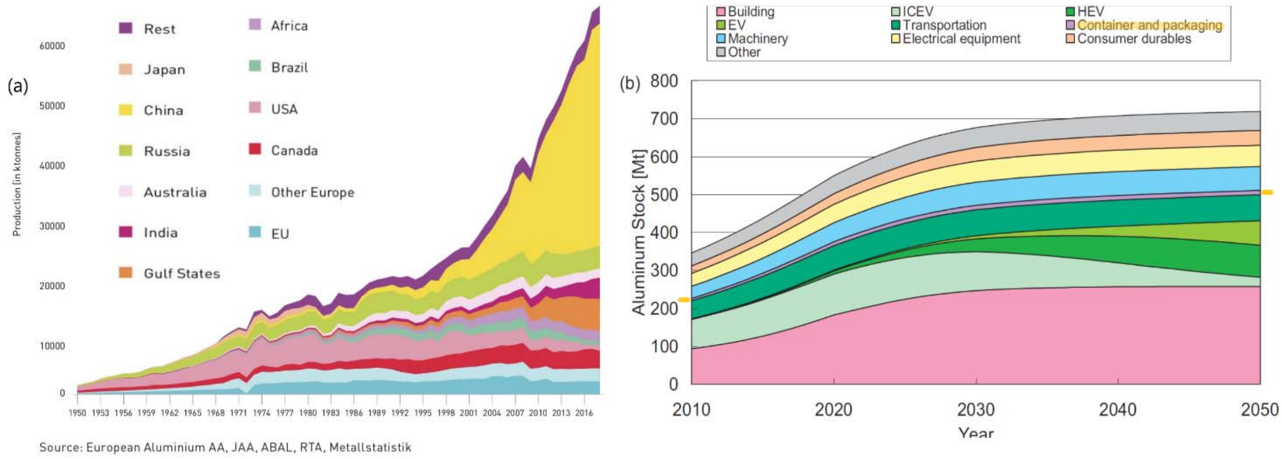

Figure 3(a): History of primary Al production by region (b): Forecast of Al stock by end-use [5]

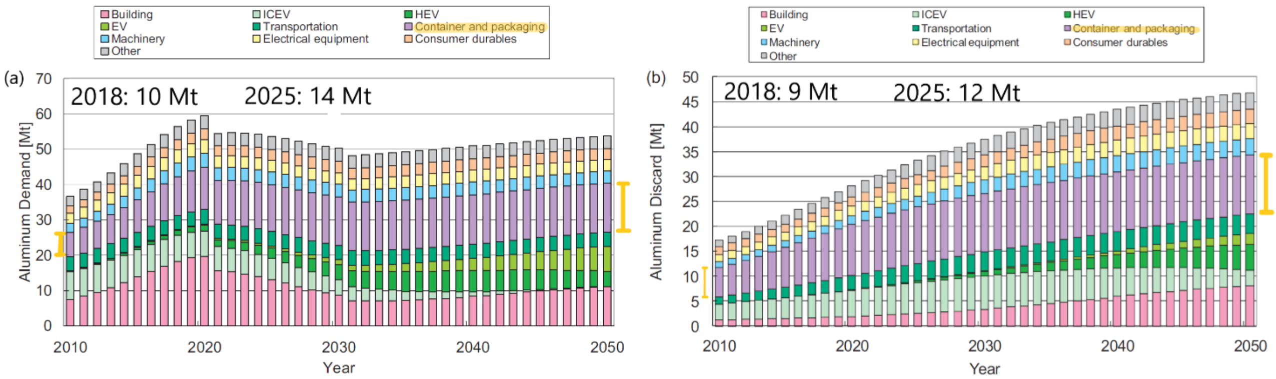

Figure 4: Forecasts of Al demand (a) and discard (b) by end-use [5]

2.5 Circular economy

Policymakers worldwide are seeking a transfer from a linear to a circular economy, Figure 5. One of the targets of the UN Sustainable Development Goal number 12 (Responsible Consumption and Production) is "*By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse*".

A circular economy aims to decrease the exploitation of natural resources and disposal of waste by reducing consumption of materials as well as reusing, repairing and recycling products. For packaging, recycling is the main way of contributing to this, as reusing and repairing is mostly unacceptable from a food safety perspective. Reducing unnecessary packaging and reducing packaging weight is also an effective measure, as long as the packaging keeps its food-preserving abilities to avoid increasing the amounts of food waste.

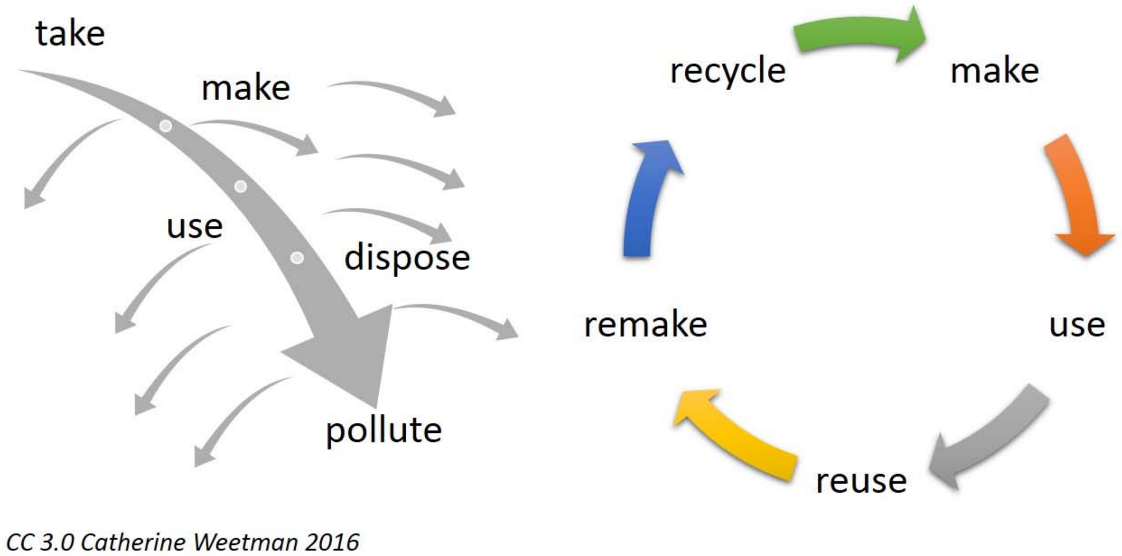

Figure 5: Linear vs. circular economy

2.6 Environmental impact

Aluminium production contributes to around 1% of the global greenhouse gas emissions [6]. In addition, emissions of toxic gases and leftover residue such as red mud also represent environmental burdens derived from the primary production of aluminium. In comparison, food wastage is estimated to contribute with 8% of the total greenhouse gas (GHG) emissions in the world [7]. Food packaging is an important mean to reduce food wastage and ensure good food quality along the value chain, so abolishing food packaging in general is unlikely to have a positive impact on GHG emissions.

Emissions of GHG has proven to be much lower for reprocessing of aluminium compared to virgin production. A study found the savings to be between 5 and 19 kg CO2e/kg Al recycled [8]. This is equivalent of the emissions from driving 38 km with a car for each kg Al recycled [1]. The main contribution to emissions in the recycling process is the reprocessing, as emissions from the waste management (sorting and collection) was found to be negligible in comparison. Variations in the estimated savings is mostly due to differences in the electricity mix, where use of electricity from renewable sources causes lower emissions both in virgin and secondary production. A study found that the environmental benefits of recycling aluminium compared to incineration with energy recovery is large enough to justify transport over considerable distances to a recycling facility [9]. However, this will depend on how the primary aluminium is produced compared to the secondary in terms of emission savings. As the primary production show a tendency of decreasing emissions, this might not be valid in the future.

[1] Considering the lowest GHG saving scenario, given that the car meets the emission requirement for new cars sold in EU after 2015, which is 130g/km.

3 China

As the world's largest aluminium producer and the largest producer of MSW, China is an interesting country to investigate when it comes to aluminium recycling. The country's immense economic growth the last decades has both led to rapid growth of Al production and demand, as well as generation of MSW. China is also a major importer of waste. As a result, both *"The world's factory"* and *"The world's scrapyard"* are terms used to describe China. Below, some key statistics are listed:

- 1-2 % of MSW is metal [10],[11]
- 20% of aluminium scrap comes from packaging [12]
- Aluminium packaging stock increased 110% from 2000 and 2005 [12]
- 17% of Al consumption comes from secondary sources [13]
- 1/3 of secondary aluminium comes from imported scrap [13]
- 25% of all available Al scrap worldwide is imported by China [14]

Waste management

China's total MSW generation has increased from 31 million tons in 1980 to 157 million tons in 2009. By 2030, it is estimated to reach more than 500 million tons yearly [15]. China's MSW consists of around 60% of food waste, which is a large percentage compared to developed countries. This can be partly explained by less packaging which decreases the durability of fresh food and makes the packaging percentage smaller [11]. Consequently, waste management initiatives in China primarily aims to separate food waste from other waste. The trend where the percentage of packaging waste increases and the food waste decreases as the economy develops is a trend seen in China, as well as in other developing countries [16]. China has no nationwide well-functioning infrastructure for MSW recycling. The government has gained increased focus on circular economy in recent years, ordinating pilot projects in several cities to improve on recycling. In recent years, many new incineration plants have opened to deal with China's increasing amounts of waste. As there is little pre-existing infrastructure except for the informal system, both traditional and innovative methods to increase recycling are being implemented [17], as we will see in the following sections.

Collection of accurate recycling statistics are complicated because of China's large informal recycling sector. An estimated 3.3-5.6 million people are involved in informal collection, processing and trading of recyclables in China's urban areas [10]. There are also uncertainties about the data used in any Chinese waste statistics, as it is often provided by the government with little insight to how the data was collected. There are indicators that implies that the officially provided recycling rates are compared to total "waste collected" and not "waste generated".

Aluminium production

The production of primary aluminium has increased rapidly in China since 2000, as well as the domestic demand for aluminium. Models predict that the domestic demand will continue to increase and peak before 2050, while primary production will peak around 2025 due to growth of secondary aluminium (Figure 6). In 2017, the primary production capacity was 42 million metric tons, while the domestic demand was 9 million metric tons less [13]. China can be facing an overcapacity issue in the near future, which needs to be addressed. Increasing exports may be a solution, provided that other countries does not increase their primary aluminium production. An upscaling of the capacity for secondary aluminium processing is also needed. Due to some extent of downcycling of aluminium scrap and loss in the aluminium loop, the demand for primary aluminium is predicted to not reach zero during this century. In a high loss scenario (much of the aluminium scrap is lost during the recycling process), primary production in China probably stabilizes around 30 million tons annually after 2050, while a low loss scenario will give an annual production of around 10 million tons [13].

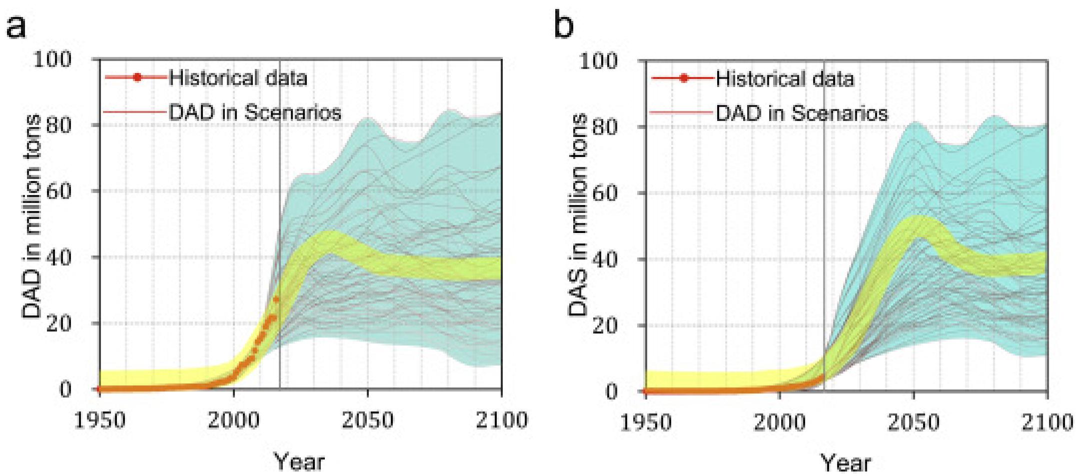

Figure 6: Domestic aluminium demand (DAD) and domestic old scrap generation (DAS) in China. Each diagram shows 81 different scenarios, and the yellow line outlines the general trends [13]

The informal system

An informal system for recycling was established in the 1980's, as a response to the dismantling of urban waste management system after the Reform and Opening process in 1978-1979. People working in the informal system are often unregistered immigrants, and their income is highly correlated with the amounts collected and the revenues obtained from selling collected items. Now, this system is widespread in urban China, and it has taken an institutional form with designated trading points (Figure 7). Waste collectors can sell their materials to so-called middlemen at these trading points. The middle men then have a storage location where the recyclables are sorted and cleaned before they are sold to the industry [18]. Estimates on how much of the MSW that is handled by the informal sector varies and is hard to calculate, but a study suggests 17-38 wt% in urban China [10]. As the food waste percentage is 60%, this means that the informal system handles almost all the recyclables if the highest estimate is true.

3.1 Consumer

Several sources report that in general, the Chinese population has little knowledge on recycling, and there is a low level of public awareness and incentives for recycling. Lack of space for multiple bins, lack of knowledge on how to sort waste and underdeveloped infrastructure is named as the main reasons for poor household recycling rates [15, 17]. The main motivation to engage in recycling, is that one can get some money from selling items to informal recyclers [17]. In Beijing and Shanghai, who were both pilot cities in a program to improve source separating, the public was overwhelmingly in favour of source separation, but only 52% and 45% respectively, participated in source separation [19].

There is probably some potential of changing the low level of awareness trough information campaigns. In a survey of citizens' attitudes toward participating in source separation in Changsha, more than 90% were consciously positive towards source separating (meaning that they believed recycling is the right thing to do morally), while the remaining reported that their compliance resulted from being law abiding or majority-following. A city-wide information campaign was conducted before the survey took place and resulted in 97.4% reported having knowledge of source separation. Still respondents had trouble with identifying symbols for certain types of waste correctly. 41% of the respondents preferred a separation that includes 4 categories, namely kitchen waste, recyclables, hazardous waste and others, while 39% wanted more categories dividing the recycling waste into subclasses. Fewer categories were significantly less supported. When the accuracy rates of different numbers of categories was investigated, the accuracy fell with the number of categories. For the recycling waste, the accuracy rate for 2 categories (recyclables and other) in Xianjia and Heyan areas was 66% and 59% respectively and fell to 51% and 37% when the number of categories was increased to five. The primary school in the experiment was a positive exception, with a 88% accuracy rate for recyclables when a four-category system was used. [20]. These findings suggest that the gap between the citizen's positive attitude and motivation to recycle and the actual ability to recycle correctly, is a challenge one must overcome in order to implement effective solid waste management systems. As the primary school did very well, education campaigns directed towards schools and other public institutions might be effectful.

Another survey investigating the most important factors in source separation behaviour found attitude to be the most important factor. Attitude was defined to consist of moral obligation and environmental knowledge, of which moral obligation was the most important. The most important factor that negatively influenced source separating behaviour was inconvenience regarding recycling being both time and space consuming. The study suggests "*cultivating residents' responsibility to protecting the environment and promoting traditional virtues of the Chinese nation*" as an effective strategy to improve residents' ability and desire to source separate their waste [21].

3.2 Collection

In the informal system, recyclables are mainly collected in two ways, either by waste pickers who search in waste bins for valuable materials, or by waste merchants who collect recyclables going from door-to-door. The recyclables are then sold on trading points and then transported to storages where they are sorted and processed before they are sold to the industry (Figure 7). A study found that 62% of all beverage cans from households in Beijing was collected by the informal system [22].

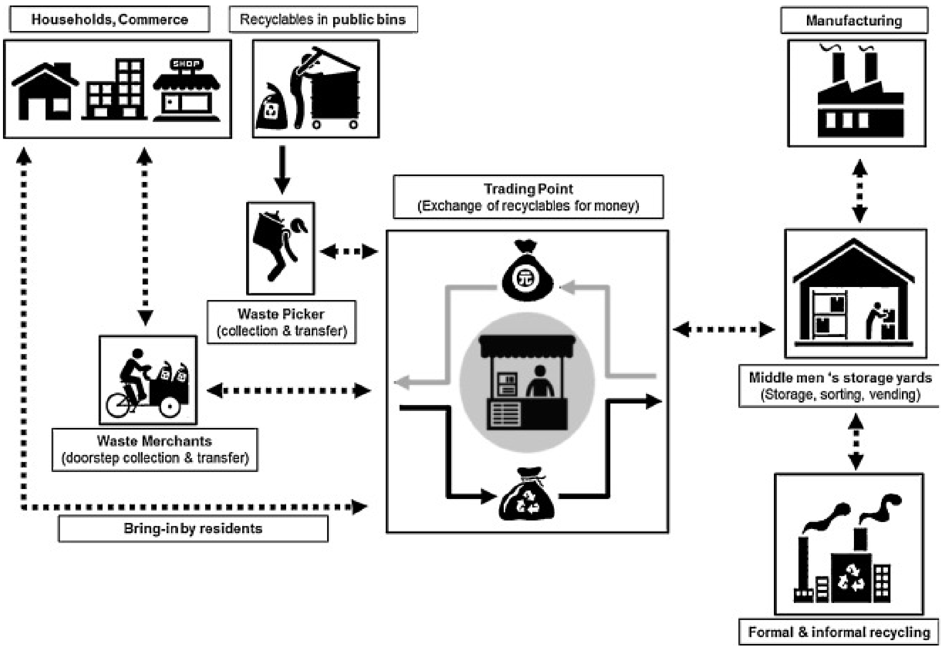

Figure 7: Schematic of the informal recycling system in Beijing [18].

The emerge of smartphones has led to several digital waste management solutions. New apps enable households to request a pick-up and payment for their recyclables, and a collector will show up at their door. This can be a method to formalize the informal recycling by employing the waste merchants as collectors in the digital solution. Reverse vending machines with compressors have also emerged as a collection option for plastic bottles. Returning a plastic bottle gives a reward on the user's bank account or transportation card. In addition to the consumer initiative, these machines can also decrease the need for transportation and labour compared to the informal recycling [23]. Coca Cola China has installed some vending machines which allows users to buy beverage cans and bottles, and to return empty ones for a reward in the same machine [24].

Recent government initiatives to increase recycling efforts among Chinese citizens includes various approaches and methods. A few cities hand out colour coded waste bags with QR-codes to improve recycling. The QR-code can be scanned by the consumer to give information about how to recycle the particular fraction. Some garbage containers are equipped with a scanner and will only open when a bag with the right code is scanned [25]. This prevents people from throwing their recycled waste in the wrong container. The recycling collector can control the contents of each bag and find out who threw the bag by scanning the QR code. This way, the collector can provide targeted guidance or penalties to consumers who fail to recycle correctly [25, 26].

Fractions

Workers in the informal system are likely to change what materials they focus on depending on market prices and possible revenues [18]. The collection rate of aluminium might therefore fluctuate as its market price fluctuates. In formal systems, co-mingling of all recyclables is common. In the pilot project started in 2000 in eight large cities, slightly different sorting fractions were used (see table below), but no subdivision of recyclables was performed on a household level [19].

Cities	Number of fractions	Fractions
Guangzhou, Shenzhen, Hangzhou, Nanjing	4	Recyclables, kitchen waste, hazardous waste, other
Shanghai	4	Recyclables, hazardous waste, wet waste, dry waste
Beijing, Guilin	3	Recyclables, kitchen waste, other
Xiamen	3	Hazardous waste, kitchen waste, other

3.3 Processing

The material flow for aluminium scrap in China for 2013 is shown in Figure 8. One third of all scrap is lost in the collection and pre-treatment stage. In comparison, only 5% is lost in the re-melting and casting stage. This bear the witness of a poorly developed collection system, as well as bad quality and impurities in collected scrap. Note that this figure includes all scrap, not only packaging scrap.

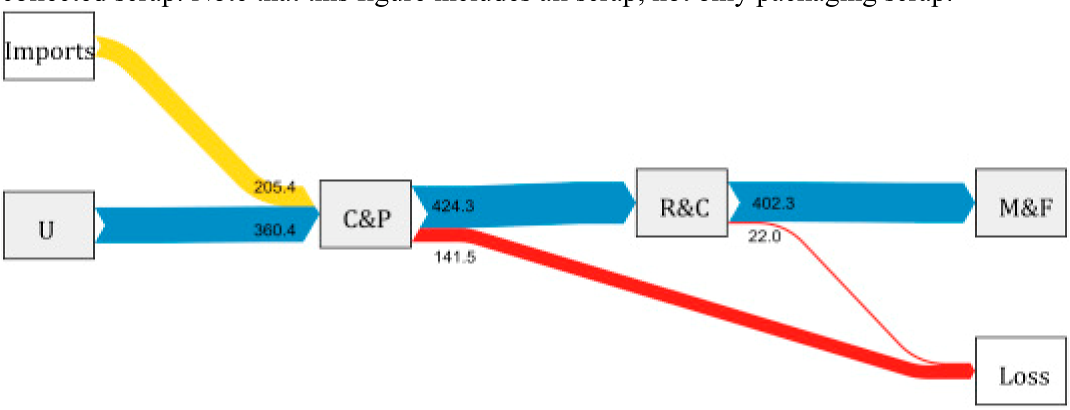

Figure 8: Material flow in the waste management and recycling stage. U=use, C&P=collection and pre-treatment, R&C=re-melting and casting, M&F=manufacturing and fabrication. Unit: 10^4 tons [27]

3.4 Economy

The informal system may create as much as 5 million jobs in Chinese cities, and the government does not need to spend money on establishing formal systems to collect recyclables. However, service availability is strongly influenced by market prices on recycled materials. As of today, much of the valuable recyclables (such as Al) are removed from waste streams collected by the formal sector, making public waste management systems less profitable. This can be addressed by locking the disposal bins, but then it is slightly less convenient for the public to recycle as they will need to unlock the bins.

Creating profitable public waste management systems has been tried locally. In 2014-2015, Ningbo was subject to a project on results-based financing for municipal solid waste funded by the World Bank. Communities that signed up would receive financial rewards based on recycling performance. Waste was separated in four streams: food, recyclables, hazardous and other, and a score was calculated based on amounts and quality of the different waste streams. A minimum score had to be obtained in order to get the reward. The intention of this reward was to give the communities an incentive to create waste management infrastructure. The incentive was to be phased out as the waste management was profitable enough to finance itself. However, the project had problems with informal recyclers taking recyclables and selling them, thus lowering the communities' profits from recycling [15].

3.4.1 Consumer incentives

The standard payment model for collection of MSW in China is a fixed fee for each household combined with government funds [28]. This does not provide any economic incentive for the citizens to recycle anything else than what they can sell to waste merchants. There has been recent interest for implementing PAYT (pay as you throw) to change this.

Households who take advantage of the informal system often have the convenience of receiving collecting service on their doorstep, as well as being able to earn money from their recyclables. Most waste merchants have a defined customer base who they keep in touch with. This convenience leads many households to use the informal system to get rid of their recyclables, at least in the big cities. It is also possible for households to personally deliver their recyclables to the local trading point where waste pickers and waste merchants sell their materials. Although this might give a higher price for the recyclables, this behaviour was found to be quite uncommon in Beijing, probably due to inconvenience [18]. These mechanisms make it challenging to implement a formal system, as the consumers habits and behaviour requires altering, in addition to building a new infrastructure.

There are also ways of being compensated for recycling without using the informal system. Bahoe district in Hefei city in China has a point-based award program to promote recycling among its citizens. Residents attach a personal QR code on each recyclable item, and recycling staff calculate the points based on category and amount and register them on the resident's account by using the QR code. Points can be exchanged to commodities from vending machines in residential compounds [26]. Ningbo is another city with a similar reward system using QR codes [25]. A study that investigated the effect of giving the residents a fixed weight based compensation for both food waste and recyclables, found that the waste separation increased from 25.4% to 87.3% [28].

3.5 Legislations

After the Reform and Opening process in 1978-79, the authorities of China mainly focused on improving the nation's economy and the living standard of the population. In the 80s and 90s, very few policies regarding MSW was issued. Around 2000, this changed (Figure 9). Although policies were issued from central authorities, the situation did not necessarily change on a local level. China is a vast country with more than 1.3 billion inhabitants, so central policies takes time to implement. In 2000, eight large cities were chosen as pilot cities for a new sorting plan. The projects were reported to have little effect [19]. In 2017, 46 cities had to establish a standard system and regulations for waste handling, with a goal of 35% recycling by 2020 [29].

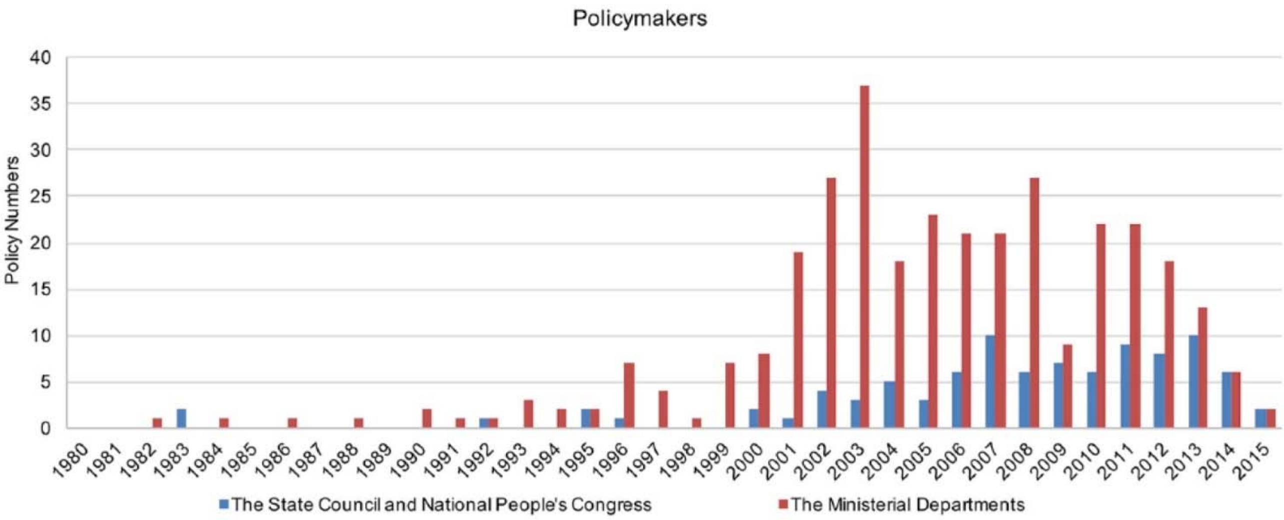

Figure 9: The number of MSW policies issued by policymakers [30]

3.5.1 Mandatory recycling

Shanghai is one of many cities which have implemented measures to reduce waste generation and improve waste separation in recent years. Mandatory recycling was implemented on the 1st of July 2019, with fines for both individuals and companies who fail to separate their waste. Some communities even have locked bins where the residents must sign in with their identification to be able to throw trash away. Data analyses can then identify which households who participates actively in recycling [31]. Because of the need of supervision, citizens cannot dispose on their waste whenever they want. Normally, collection points will be open between 7 and 10 in the morning, and from 5 to 8 in the evening. As the mandatory recycling in Shanghai is an initiative from the federal government, more cities will probably implement this in the years to come.

Recent news from Shanghai

As Shanghai is the first Chinese city to enforce recycling on a large scale, some news reports from its first month is presented here.

People seem to have some trouble with identifying the right category for their waste. An example causing confusion is that chicken bones belong in the wet waste bin, while pig bones belong in the dry waste bin. This has led to the creation of this rule of thumb: *If a pig can eat it, it goes into the wet bin. If a pig cannot, it is dry waste. If a pig is likely to die from eating it, the waste is hazardous. If you could sell it and buy a pig with the funds, it is recyclable waste.* [32]

The city has recruited tens of thousands of volunteers, many of them retired elderly, as supervisors on the waste collection sites. A young woman admitted having strangled an elderly supervisor until she fainted because of an argument about correct sorting of waste. The young woman had to spend three days in detention, while the elderly supervisor had to spend a night at a hospital [33].

This woman is not the only one being frustrated about the new regulations. There have been reports of people claiming to give up cooking or eating take-away at home to avoid the difficulties of sorting their trash. One citizen even tried to illegally ship his waste out of the city. Peoples' recycling efforts in Shanghai are now motivated by fines and sanctions rather than environmental consciousness. The government's approach of enforcing recycling in a "top-down" approach instead of leaving the local municipalities to deal with the issue, has lead a lecturer in a China Studies university department to call it "eco-dictatorship" [32].

3.6 China summary

China's public recycling system can be said to still be in its infancy, at least compared to most developed countries. Rapidly growing waste amounts have increased the awareness of both the public and the government regarding recycling, leading to implementations of innovative pilot projects in many communities. A challenge is that Chinese citizens seems to expect a compensation for their effort in recycling, which is not supported by the flat fees on waste management. The informal system has traditionally provided economic incentives to participate in recycling.

The informal system has a positive impact as it creates jobs and is self-financed, but it also undermines the implementation of a public well-functioning system. Valuable items, such as Al packaging, is diverted from public collection services by the informal system, and thus prevents the public system from reducing cost by selling these materials. In addition, the informal system does not provide a consistent service, as the materials collected often fluctuate based on their market prices. On the other hand, recycling rates of aluminium is probably very high as it is a material that is nearly guaranteed to create revenue for informal waste workers. However, there is next to impossible to find statistics on these rates as it is not monitored by the government.

Many of the innovative pilot projects includes the use of QR-coded bags. This has a dual benefit, making it possible to both apply economic incentives in forms of awards for source separation, as well as controlling the quality and sanction those who sort incorrectly. In addition, the code can be an easy and available source of information on how to sort for the citizens who own a smartphone.

The Chinese government can implement changes in an impressive short time. Ambitions regarding recycling has recently been declared, which might result in a rapid increase of recycling rates in China. Shanghai is the most prominent example of the government's demand for change. Here, recycling became mandatory on the 1st of July 2019. Facilitating this, waste bins have been installed all over the city during the past few months, and tens of thousands have been recruited as supervisors who ensure that everyone is sorting correctly. The development of recycling in China might be interesting to keep an eye on in the future.

4 United States

The rate of recycling as well as the legislation, varies to a large degree from state to state and from city to city. While San Francisco only sends 20% of its waste to landfills or incinerators, Chicago sends 90% [34]. Therefore, this section will both include an overall picture of the recycling situation in the US, as well as separate cases from different regions. Much of US recycling relies on exporting materials for treatment. This is more important for materials such as plastics and cardboard, but a lot of aluminium scrap is also exported (Figure 10b). Commonly, ships which bring goods to the US from countries such as China returns with recyclable waste from the US instead of returning empty.
The US consumes large amounts of aluminium and produces some. In 2010, the aluminium stock in the US was 150 Mt, more than any other country in the world [35]. The primary aluminium production in the US is declining, while secondary production is stable (Figure 10a). Below are some more key statistics:

- The recycling rate of aluminium packaging was 36% in 2015 [36].
- Beverage cans was the most recycled type of packaging, with a recycling rate of 55% [36].
- The total aluminium consumption in the US in 2016 was 10,5 million metric tonnes [37].
- 20% of the aluminium consumption was containers and packaging [37].
- 9% of the MSW is metal [16].
- In 2016, the aluminium recycling industry created 175,000 jobs with almost 6 billion $ in wages and more than 1 billion $ in tax [38].

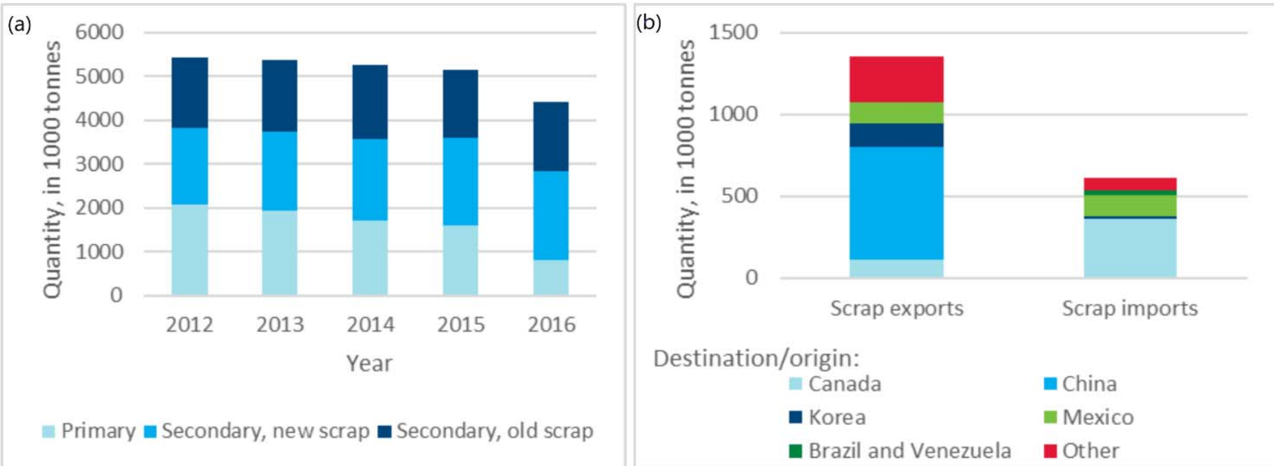

Figure 10 (a): Al production in the US (b): import and export of Al scrap in 2016 [36]

4.1 Consumer

A study on recycling behaviour found that US citizens recycle more when there is a curbside recycling program present, and especially when this program is mandatory. Lack of storage space for materials to be recycled was found to be an obstacle. Large households and households with at least one resident over the age of 65 was also more likely to recycle [39]. Other studies also support that recycling participation increases with age [40-42]. Regarding the use of drop-off points for recycling, the usage has been shown to decrease as the distance from the residence increases [40]. The same study also found that the use of drop-off points does not decrease when curbside collection is available. This suggests that materials that are not collected at the curbside can still be collected at drop-off point if the location of the drop-off is convenient.

Implementation of mandatory recycling, as well as volume-based fees on residual waste have also been shown to increase recycling [41]. However, convenience has been found to be a more important factor than economic incentives, with the exception of deposit-return systems [42].

4.2 Collection

Curbside collection is the most common collection scheme for recyclable waste, according to a nationwide study conducted in 2015-2016. Figure 11 shows that 73% of US citizens had access to such a curbside collection program, while 21% had access to a drop-off program only. 6% did not have access to any recycling program. Most of the curbside programs are universal, while some require the citizens to subscribe to a program of their own choice or have an opt-in solution where citizens must take action to participate in the provided program. Of the total population with access to a opt in or subscription program, only 38% and 30% respectively, chose a subscription. Making recycling programs mandatory can thus be a mean to increase recycling. In single-family based curbside collection schemes, 89% had a single-stream collection system, while 10% had access to a double-stream system. Single-stream recycling implies that all recyclable materials is disposed in the same bin. In a double stream, recyclables are often divided into fibers (paper and cardboard) and containers. A common argument for implementing single-stream systems is that it can increase collection rates due to its convenience for the consumer, and that it decreases collection costs as there are only one bin of recyclables to empty. Criticism towards single-stream collection is that it decreases consumer awareness and might lead to disposal of non-recyclable items in the recyclables' bin (such as metalized plastic).

In Canada, dual-stream recycling is more abundant than in the US. A Canadian study [43] that focused on finding the performance differences between single-stream and dual-stream recycling found some interesting results:

- Single-stream gave a 4% higher recycling rates among households
- Collection is slightly cheaper for a single-stream system
- Processing cost is nearly 50% higher for single-stream compared to dual-stream
- Revenue from sold material is 10% lower for single-stream
- In total, single stream is 28% more expensive than dual-stream

These findings suggest that the benefits from single-stream recycling are lower than expected, especially when it comes to economy. The difference in what is efficiently recycled in the systems was not investigated, as the "recycling rate" here refers to the amount of recyclable items that was placed in the recycling bin. The fact that the revenue from sold material was lower in the single-stream case indicates that the increased collection might be outweighed by material loss and downgrading in the recycling process. This means that increased recycling rates might not mean that more material gets effectively recycled in a single-stream system.

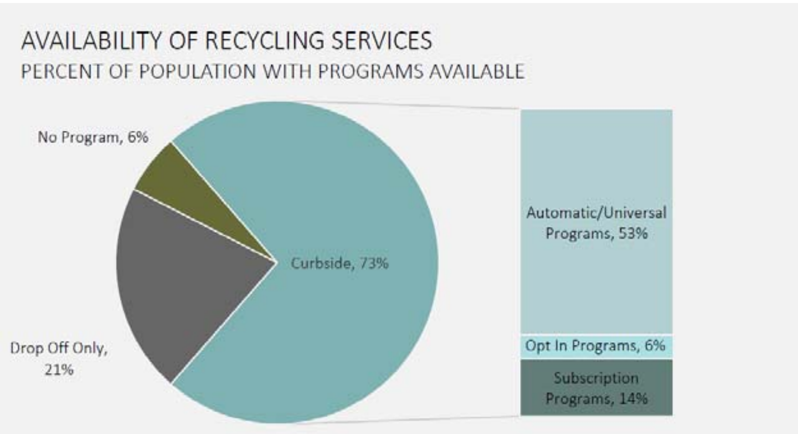

Figure 11: Overview of recycling program availability in the US [44]

4.3 Processing

As most of the recyclables in the US are mixed in one container, MRFs need facilities to divide the incoming waste into separate streams. An example of such a sorting facility is shown in Figure 12. There is a risk of aluminium cans being sorted incorrectly in the automatic MRFs, especially in MRFs handling a lot of different material types in a single stream. Sources of sorting errors can be flat aluminium pieces sorted as a 2D material at the star screen, which causes it to end up in the paper bale. Small pieces of aluminium may also falsely be identified as glass. Some MRFs in the US have installed a second eddy current separator in their facilities to avoid some of this loss [45]. The aluminium fraction is compressed into large bales and sold to secondary aluminium plants. There are nearly 2000 MRFs in the US, and around 50 secondary aluminium plants [46, 47].

Interviews with managers at MRFs and processing plants disclosed that aluminium beverage cans are by far the most favourable item for them to recycle, due to its consistent market, easy sorting and high value. However, concerns were raised regarding additions to the packaging. Examples of additions that are common for beverage cans are

- Resealable lids (often made of plastic)
- Plastic widgets (such as the plastic ball inside Guinness beer cans)
- Stickers
- Shrink sleeve labels[2]

These additions can make it more difficult to control furnace temperature and require the mill to operate at a slower pace. It also gives a less predictable quality and yield of recycled aluminium. Stickers and shrink-sleeves can cause sorting problems, risking loss of the aluminium if it ends up in the wrong stream. Other aluminium packaging items also raises some concern with MRFs and processors. Aerosol cans can be a fire hazard if they are not sufficiently emptied. Foil and trays often contain contamination from food residue and thus decreases the bale quality [48].

[2] method replacing printed design on cans. An oversized label is placed around a can like a sleeve. High temperature makes it shrink and sit tightly around the can. Often used by craft breweries because they can be ordered in smaller quantities than printed cans.

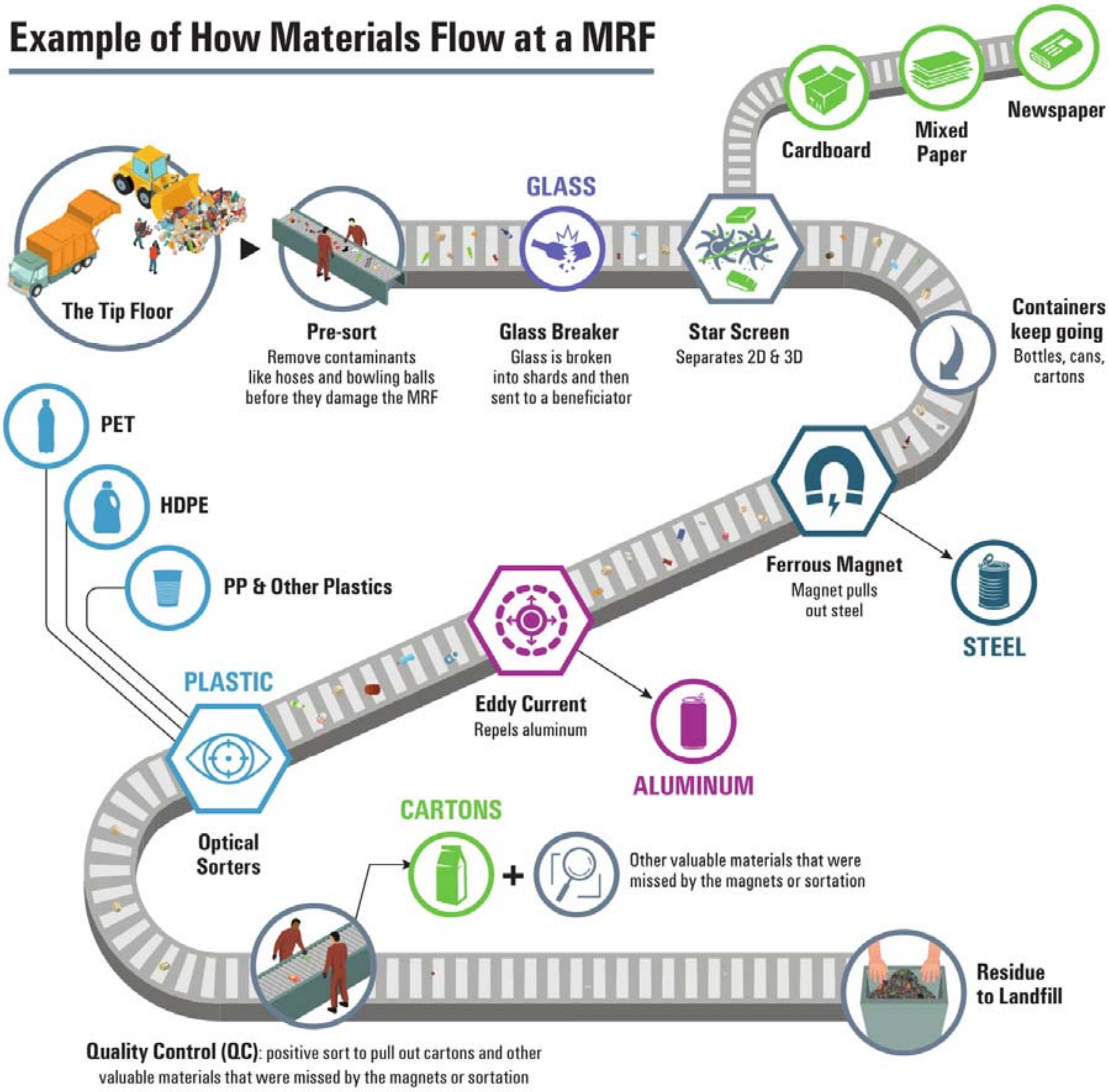

Figure 12: Material flow in a typical MRF. Source: http://astrx.org/resources/astrx-study-of-material-recoverability/

4.4 Economy

In the US, the recycling industry is highly dependent on profit for the collectors and MRF facilities. China's ban on importing plastics and paper have severely damaged the recycling enterprises in many US cities, as the recycling companies have raised their fees because they are unable to export materials [49]. They also send more materials to landfill and incineration because this is often less costly than to recycle them in the US. This problem does not affect aluminium directly, because collectors and MRFs get more money from selling Al in the US than they pay to collect and process it. However, aluminium is collected together with all the other materials, so increased landfilling and incineration of other recyclables also means increased landfilling and incineration of aluminium packaging. Recycling rates have historically followed the aluminium price to a certain degree, both for aluminium scrap recycling in general and in the specific case of beverage cans (Figure 13). Some of this effect might come from storage of aluminium scrap until the price rises again, but this depends on available storage space.

EPR is widespread across Europe and is also being introduced in several other countries across the world. There are no EPR laws on packaging in the US today, meaning the producers do not have to pay recycling fees on their packaging. This means that the costs of providing recycling programs must be covered by states, municipalities and consumers entirely. However, law proposals on EPR are on the way in some states [50].

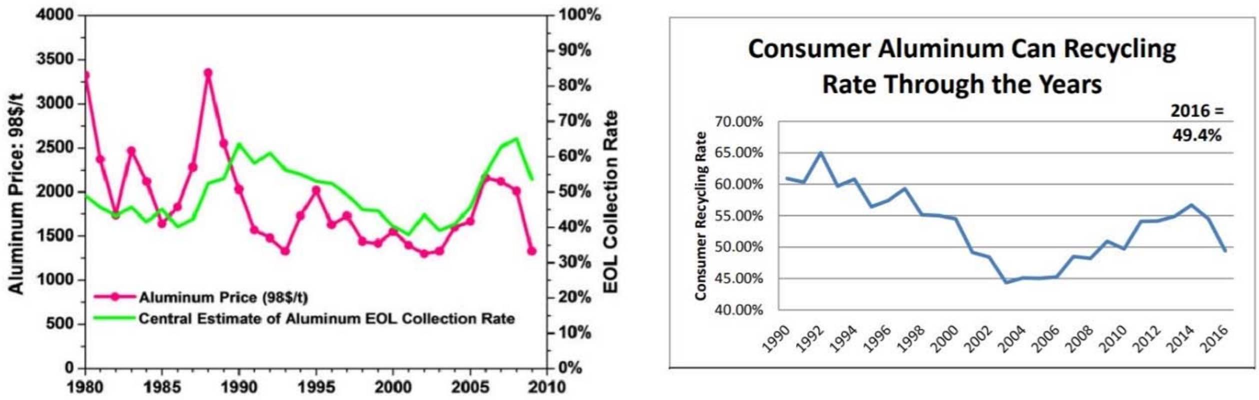

Figure 13: Collection rate of all Al scrap and price (left) and collection rate of aluminium cans (right) [51, 52].

4.4.1 Consumer incentives

Ten states in the US have so-called "Bottle bills", which are deposit schemes for beverage bottles and cans. The deposit refund is typically 5 or 10 cents per item, and the recycling rates for beverage containers are significantly larger in states with a deposit scheme (Figure 14). Deposit schemes also produce cleaner waste streams than single-stream curbside recycling, which is beneficial for MRFs and processors [48]. In all but one of the states, the bottle bill was implemented during the 70's and 80's. Producers, such as Coca Cola, have often opposed bottle bill proposals in other states.

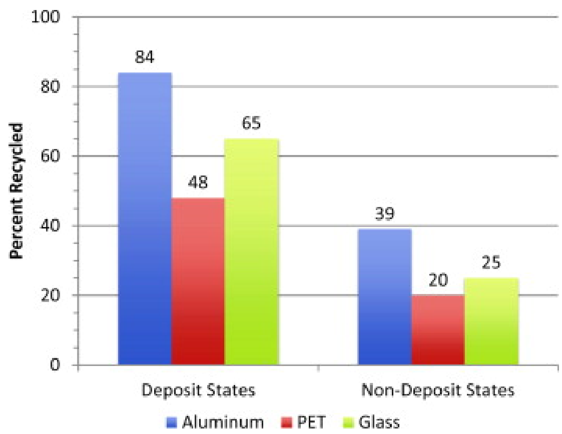

Figure 14: Comparison of deposit rates in US states with and without deposit schemes [46]

PAYT is a common model in the US which aims to create an economic incentive to generate less waste and recycle more. Typically, the household only pays for the residual waste bin, while recycle bins are collected for free. The price on the waste often depends on the volume of the waste bin or the number of bags. Weight based pricing is also an option, but it is less common.

4.5 Legislations

There are few legislations concerning packaging waste on a federal level in the US. There are laws aiming at ensuring collection and proper treatment of MSW, such as regulations on how landfills should be managed, as well as emission limits for incinerators. However, laws addressing recycling rates are rare, except for bottle bills in ten US states.

San Francisco – Becoming a zero-waste city

Making recycling mandatory is just one of the steps that the city of San Francisco has taken in its pursuit to become a zero-waste city by 2020. As the first American city, San Francisco pledged to become zero waste already in 2003. Zero waste is defined as diverting 100% of the waste from landfills and incinerators by recycling and composting the waste. As of 2018, the recycling rate of San Francisco was reported to be 80%. In addition to legislation, more measures have also been taken to ensure a high recycling rate. This includes a volume-based fee on waste containers and tight cooperation between the city council and Recology, which is the company collecting and processing the waste in San Francisco. As opposed to many other US cities, only one company operates in San Francisco, making collaboration with authorities easier [53]. Diverting the last 20% seems to be more of a challenge. According to the authorities, 50% of the content in the residual waste bins could be either recycled or composted. The rest is not recyclable and demands the producers to change their design for the item to be recyclable.

4.6 United States summary

The recycling industry in the US often operates under free market conditions. This can be an obstacle for increasing the recycling rates, as it is often less costly to landfill or incinerate many recyclable materials than to recycle them. A common strategy has been to sell recyclable waste to China as it is cheaper to treat it there. Recently, China issued import bans on contaminated recyclables. This has made it difficult for US waste collectors and processors to stay profitable, which have resulted in increase of landfilling and incineration in many areas. Although aluminium packaging scrap can be sold for a revenue and re-melted in the US, the increase of incineration and landfill also affects recycling of aluminium packaging because it is often collected in the same stream as other recyclables.

US citizens generally have good access to curbside recycling, where all recyclables are typically co-mingled. New MRFs are often equipped with technology able to automatically separate the recyclables into pure material streams. Unfortunately, data about the efficiency of these sorting facilities have not been obtained.

From an overall perspective, the United States does not seem to have much ambition when it comes to recycling. Laws, directives and financial means are absent on a federal level. However, ambitious targets and legislations on recycling has been set by some states and cities, apparently with good results. The zero-waste target of San Francisco has led to 80% diversion from landfilling and incineration. Deposit-return systems are implemented in 10 states and increases recycling rates of aluminium cans from 39% to 84% on average.

5 The European Union

Some of the EU member states are performing among the world's best when it comes to recycling. The waste management systems in these countries have existed for decades and are generally well developed. They are characterized by a high level of government regulations, as well as thorough reporting systems which provide a good overlook on how the systems perform. Some of these regulations are mandatory for all EU member states. Still, some of the member states, especially new members from eastern parts of Europe, have relatively low recycling rates. Many EU member states have high recycling rates for Al, especially from beverage cans. However, there is potential to recover a lot more, as overall recycling rate for Al in MSW was shown to be 39% in Austria (Figure 15a). Other EU and European statistics are:

- Europe imports half of its primary Al consumption [54]
- Primary Al produced in Europe have average GHG emissions of 7 kg CO_2e / kg Al [54]
  - The world average is 18 kg CO_2e / kg Al, while China's is 20 kg CO_2e / kg Al [54]
- 53% of Al produced in Europe comes from recycled resources [54]
- 17% of Al end-use is packaging [55]
- 900 thousand tonnes, or 10% of Europe's Al scrap was exported in 2017. Most of the exported Al scrap ends up in Asian countries such as China, India and Pakistan. [54]
- 3% of MSW is metal [16]

The main reason that European primary aluminium has low emissions is that more than half of Europe's primary aluminium is produced in Norway and Iceland, which both have high availability of electricity from renewable sources. State-of-the-art technology and government regulations also contribute to this difference. Forecasts of the European demand for aluminium (Figure 15b) predicts that domestic primary production will stay approximately at today's level. The increasing demand will be met primarily by producing more secondary aluminium, in addition to a slight increase in imports of primary aluminium.

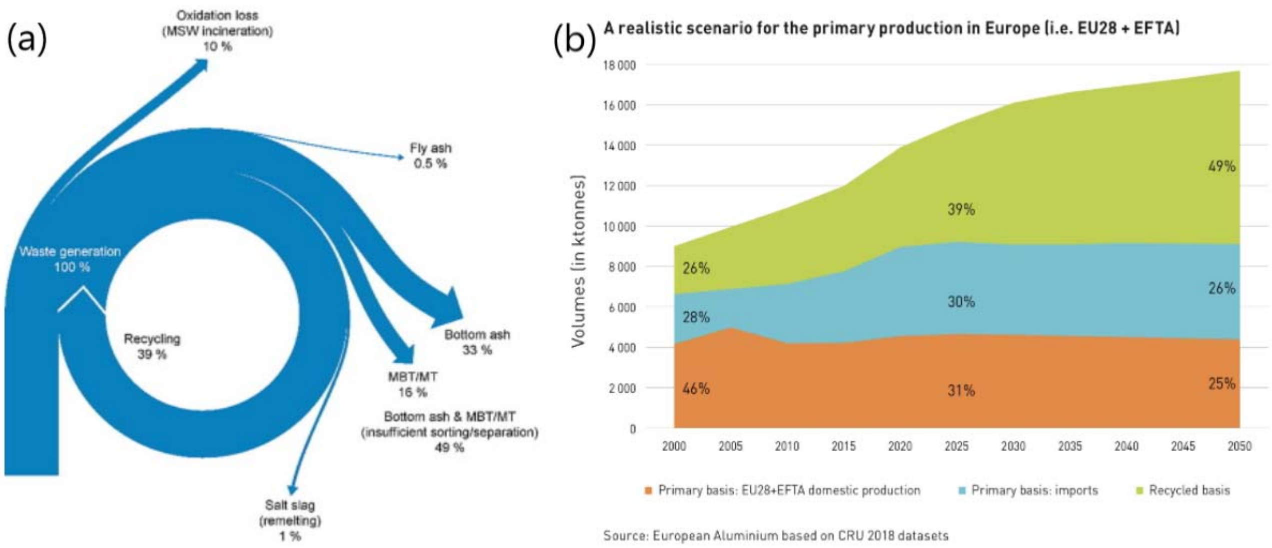

Figure 15 (a): Al loss in recycling of Al packaging in Austria 2013 [2], (b): Forecast of the Al demand in Europe and its sources [48]

5.1 Consumer

A survey conducted in Sweden found that Swedish households recycle two thirds of their packaging waste, where metal was the most recycled material with 77% of the respondents reporting that they recycle all metal packaging [56]. It was shown that moral norms are important for explaining household recycling efforts, with moral obligation, perceived positive impacts (on the environment) and beliefs about others' behaviour as contributing factors. However, the importance of these norms decreased as property-close recycling was introduced. This suggests that if recycling is convenient, participation is less dependent on environmental awareness and self-imposed moral obligations. The study also found that recycling rates for all materials increased with increasing age, and that residents in multi-family dwellings recycle less metal than residents in single-family dwellings. A possible explanation might be that single-family dwellings often have more storage space and easier access to cars, making it less inconvenient to recycle metal at a drop-off point. A comparison between Bulgarian and Swedish students showed that attitude towards recycling is the most important determinant for participation in a well-functioning recycling program, while ability to participate was the most important determinant in a underdeveloped waste management system [57]. While the two groups' attitudes towards recycling were similar, the participation rate was 30% higher among the Swedish students. This indicates that poor conditions can prevent individuals from recycling, regardless of their positive attitude and intentions to participate. This study also suggests that over time, a well-managed waste system imposes the citizens to feel expectations from the surroundings to recycle. The basis for this assumption was that the respondents in Sweden, which has a mature decade-lasting recycling system, the respondents reported more frequently that they felt that their family and peers expected them to recycle. In Bulgaria, where recycling is relatively new, fewer felt these expectations. Sweden and Bulgaria are subject to the same waste management directives imposed by the EU.

5.2 Collection

Multiple stream collection of recyclables is far more common in the EU than in China and the US. In western and northern Europe, collection systems have been under development for decades, while newer members of the union have implemented systems quite recently. Therefore, a large variation is seen across the EU where the best performing countries recycle 80% of their packaging, and the poorest performers recycle 40% [58]. As waste collection is often the responsibility of the municipality, collection schemes can also vary greatly within each country. The extremities are only one bin for mixed waste in curbside collection and recyclable collection only on drop-off points, and up to five bins in curbside collection including bio-waste, mixed waste and three different streams of recyclables. Co-mingling of metal and plastic is practised in five member states [59], and deposit schemes for beverage containers are practised by several member states. In UK, Ireland and France, single-stream comingled collection of recyclables is the most common option, followed by dual-stream comingled collection [60]. In most countries, collection of residual waste and selected recyclables are collected at the curbside, while other recyclables must be taken to a drop-off point or a recycling centre. Curbside sort, where recyclables are comingled in one bin and then sorted by waste collection personnel at the curb was common in UK in 2008. However, personnel cost is likely to cause this method to be less widespread in the future. It is noteworthy that in all the cases investigated, metal is co-mingled with at least one other material in curbside collection. Probable reasons are that the fraction of metal in MSW is low (1-5%) and that it is relatively easy to separate it from other materials in an automated MRF.

A comparison of the effects on introducing separate food collection and a weight-based fee on unsorted waste in Sweden showed that separate food collection decreased the amount of unsorted waste, as well as it increased the amount of recyclables. Curbside collection of recyclables increases the collected amount compared to a drop-off solution [61]. A weight based fee also decreased unsorted waste, but to a lesser degree than separate food collection [61, 62]. A suggested explanation is that introduction of separate food collection signals that source separation is important, and thus encourages citizens to do so. However, these two incentives can be used simultaneously where the weight-based fee acts as a tax on unsorted waste, while food waste collection acts as a subsidy as it enables the citizens to reduce the weight of the unsorted garbage. A model predicting the most favourable collection system in Aarhus, Denmark, found that curbside collection only would give the best recycling rates, and also the largest economical savings for the government [9].

5.3 Processing

The diversity of collection systems across Europe demands diverse MRFs. Some typical cases are listed and described here. [60] provides an overview over different MRF technologies and more details about their performance.

- In southern Europe, the climate requires the waste to be collected frequently. This facilitates a low cross contamination, enabling extraction of recyclables from residual waste. Metal is often extracted with magnets and eddy currents, while other materials are typically sorted out manually.
- Some regions use both source separation to obtain clean waste streams, as well as residual waste processing facilities with the ability to extract some of the remaining recyclables.
- German plants for sorting of lightweight packaging (plastic, metal containers and beverage cartons) have a recovery rate for aluminium between 60% and 90%, with an average of 80%. A model for German lightweight packaging sorting plants estimates the recovery of non-ferrous metals in an advanced plant to be 80% under designed operation and 40% under typical operation. Typical operation often involves overload where the plant focuses on processing as much material as possible instead of focusing on quality [63].
- A case study for Al household waste in Austria found that separate collection of Al packaging contributed the most to secondary Al production. Most of the Al in residual waste (RW) was incinerated, where oxidation losses and insufficient recovery from bottom ash led to a large proportion going to landfill (Figure 16). Technology used to extract Al from bottom ash was able to collect particles larger than 3-4 mm [2].
- In Germany, metalized films are sorted as regular aluminium packaging. The plastic layer will be removed in a pyrolysis step, also removing lacquer and other impurities from the aluminium scrap. Some aluminium will also be lost due to oxidation [1]. This method avoids economic challenges as it utilizes an already existing processing line, but given an aluminium content of 20%, more than 80% of the packaging will not be recycled into new plastic, but rather used for energy applications.

There are limited publications on the cost difference between sorting recyclables and leaving them in the residual waste to be sorted centrally. Central sorting seems to be slightly more expensive despite reduced collection costs. However, increased material yield from central sorting was not considered. An argument against abandoning source separation where it is already established is that this might lead the population to be less aware of their own waste generation [60].

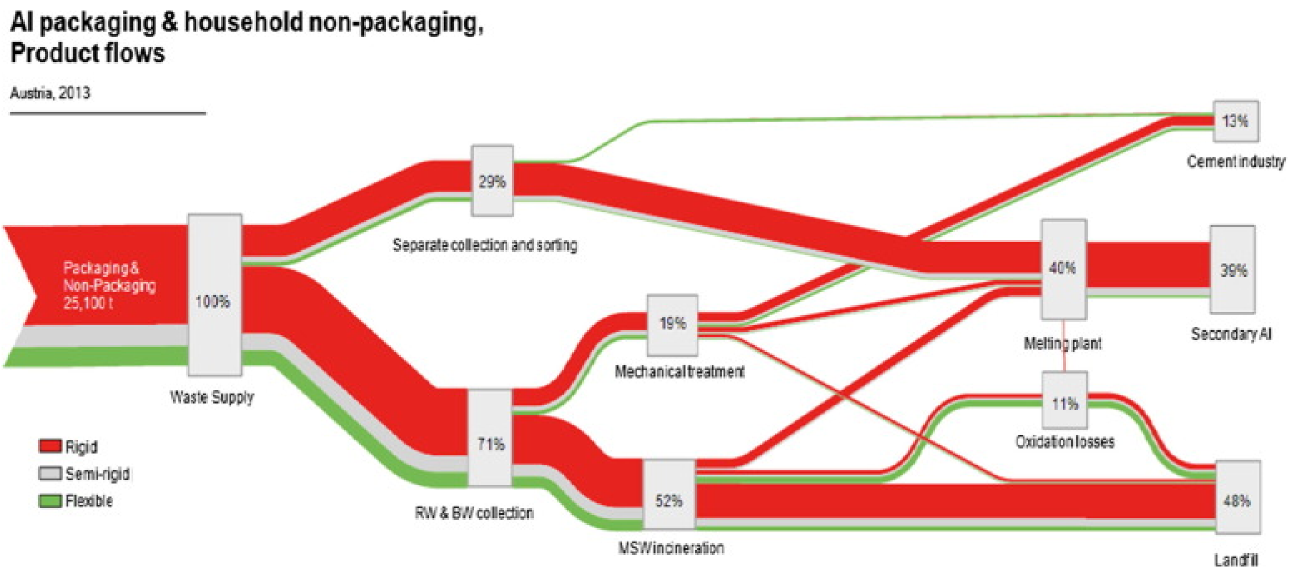

Figure 16: Material flow of Al packaging and household non-packaging in Austria, 2013[2].

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5.4 Economy

Cost efficiency analyses of German lightweight packaging sorting plants show that sales of materials are not enough to outweigh operational costs and disposal costs of residues. This deficit is covered by the extended producer responsibility fees [63].

Extended producer responsibility (EPR) for packaging waste is widespread across the EU. It started in Germany in 1990 and has now spread to 31 European countries. This is a principle where the producer is responsible for the treatment of their EoL products. For packaging waste, most producers delegate this responsibility to producer responsibility organizations. By paying a fee to the organization, the producer is assured that its product is properly treated at its EoL. The organization then redirects these funds to the waste management system. In the case of PRO Europe, which is an umbrella organization for packaging recovery in Europe, producers pay a license to put the Green Dot mark on their packaging. The fact that Denmark does not have an EPR system is worth noting. Still, Denmark enjoy high recycling rates.

The EPR system is implemented in different ways across the European nations. An analysis [64] of different approaches suggests that systems where the responsibility of recycling packaging is centralized (such as the Duales system in Germany) results in higher recycling rates than when municipalities have the sole responsibility (as is the case in UK). Moreover, systems where local authorities have been engaged in the implementation of the EPR system performs better, according to the study.

Traditionally, the EPR fees are based on a combination of unit- and weight-based pricing, dependent on the type of packaging material. These fees are set by the individual producer responsibility organizations and aims to reflect the cost of collecting and treating a given kind of packaging. The EU has recently started focusing on so-called eco-modulated EPR fees in which the recyclability of the packaging is reflected in the fee. This is already implemented in some of the member countries, such as France and Italy [65]. Eco-modulation aims to create an economic incentive for producers to use and design packaging that can easily and effectively be recycled. Eco-modulation will likely influence the store price on the product, so that consumers will save money by buying products with recyclable packaging.

5.4.1 Consumer incentives

Seven EU capitals use PAYT schemes. The common model is to have a fee on the mixed waste, either weight, volume, frequency or sack based, and provide free collection or drop-off for recyclables and bio-waste. The free collection is cross financed by the fee on mixed waste, encouraging increased separation rates. The EU capital cities using PAYT schemes have higher recycling rates (35% on average) than those who don't, and the cities with flat rates perform the worst (17% on average) [59].

Several European nations have deposit-return system in place for aluminium beverage cans. Many of these systems have been in place for 30 years and have resulted in aluminium can recycling rates of up to 95%. Belgium also manages to collect more than 90% of their aluminium cans without having a deposit-return system. However, it may be overestimated due to residue on cans. In the UK, it is possible to return aluminium cans directly to scrap dealers who will pay around 50p per kg.

5.5 Legislations

The first legislations on waste made by the European Union was the Waste Framework Directive from 1975, which was updated in 1991 and 2008. The first directive aimed at implementing the principles of the waste hierarchy (Figure 17). The packaging and packaging waste directive was issued in 1994, and both directives were reviewed in 2018. The circular economy package was adopted in 2015. It aims to improve recycling rates by setting recycling targets for specific materials (Figure 18) It also redefines what can be counted as recycling. Amounts of recycled materials can no longer be measured at the point of collection but can only include what is effectively recycled. Energy recovered from incineration cannot be reported as recycling but recovered metal from bottom ashes still counts. The European Waste Framework Directive required all member states to set up separate collection systems for paper, metal, plastic and glass by 2015.

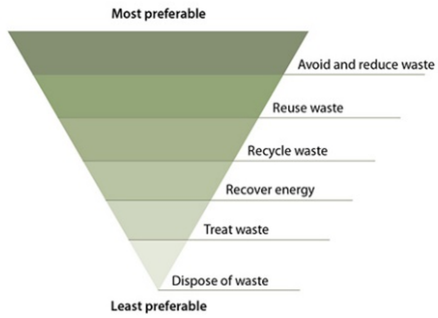

Figure 17: The waste hierarchy

Ljubljana – Europe's first zero waste capital

When Slovenia became an EU member in 2004, there was little recycling infrastructure in the country. Now, its capital Ljubljana is one of the best performing cities in Europe when it comes to recycling rate. The city's waste is separated into curbside bins for recyclables, food waste and residual waste. The city's waste collector began collecting residual waste less frequently, which led to overfilled bins, media criticism and unhappy residents. Instead of giving in to the demands, the collector communicated the importance of this change by showing to local media how much of the waste in the residual waste bins belonged in the recyclable bin. In 2014, 61% of Ljubljana's waste was composted or recycled, compared to less than 10% in 2004. In 2014, Ljubljana adopted a zero waste strategy, committing to recycle or compost 78% of all waste by 2025 [66].

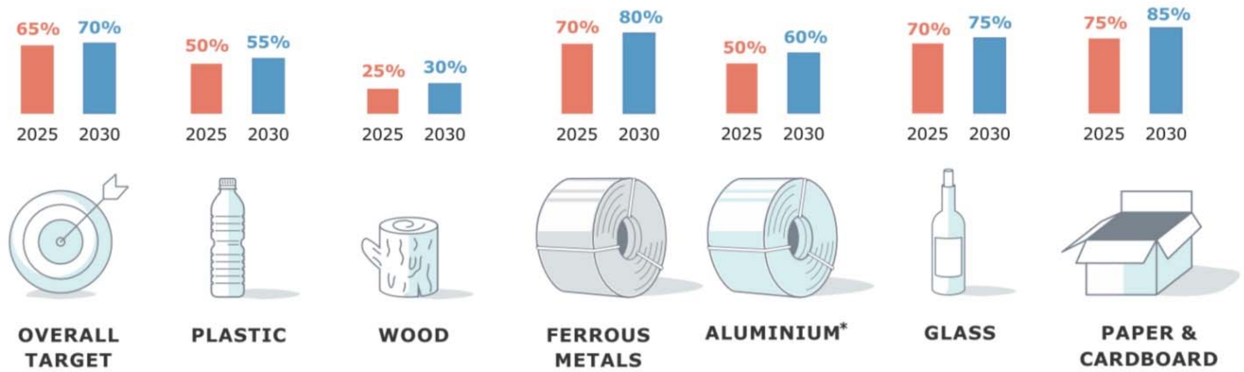

Figure 18: Recycling targets that must be achieved by all member states individually *source: metalpackagingeurope.org*

5.6 European Union summary

European citizens are often expected so source separate their waste into many different fractions. Some also have different collection points for different recyclables. Incineration with energy recovery is widespread across Europe as an alternative to landfilling. The actual recovery of Al from bottom ash is however lower than what is theoretically possible, due to insufficient equipment for extracting particles, especially the small ones.

Deposit-refund for beverage containers has proven to be successful in Europe, with collection rates over 95% for some of the countries. PAYT-schemes are also emerging as an economic incentive for consumers to recycle more.

The EU recycling market is under the influence of EPR, which provides conditions that differ from the free market. As well as ensuring treatment of packaging waste regardless of their market value, they can also be designed to create incentives for producers to make packaging that are easier to recycle.

The EU has implemented legislations on packaging waste for many years and has also set ambitious targets that its member nations must reach. The new directions for measuring recycling are especially interesting. As they are implemented, it will be easier to see how much of the collected recyclables that are actually recycled. This in turn will make it easier to identify aspects of the recycling process that should be improved.

6 Region-independent cases

6.1 Coffee capsule recycling

A challenging and common food packaging is coffee capsules. Some capsules are made of mostly plastics or a plastic cup and aluminium foil. The world leading coffee capsule producer Nespresso, however, makes their capsules entirely out of aluminium. Coffee grindings inside the capsule is a challenge when it comes to recycling. If the consumer disassembles the capsule and empties the coffee at home, the capsules can in most cases be recycled in the normal metal recycling system. However, this is not very convenient, and one cannot expect to get high recycling rates from this approach. Addressing this, Nespresso has made their own recycling program where capsules are collected in a separate stream. Consumers can deliver their used capsules to a local Nespresso store, or send it by mail in a pre-ordered bag. The capsules are then separated from the coffee (Figure 19), and the coffee is composted while the aluminium is pressed into bales and re-melted. In 2016, Nespresso reported a recycling rate of 24.6% and claimed to have recycling programs present in 44 countries [67].

Figure 19: facility for recycling of coffee capsules

6.2 Informative labelling

How2Recycle, a project started in the US by the Sustainable Packaging Coalition, has developed a labelling system for packaging with information on how to recycle it. The labels can be used by all its members, which in return pay a subscription fee based on their revenue. Among current members, one can find large companies such as Coca Cola Company, Walmart, Amazon, Unilever and Nestlé. An example of what information the label contains can be seen in Figure 20. A limitation to a labelling system like this is the differences in local collection systems, which may have different requirements to the preparing and recycling done by the consumer.

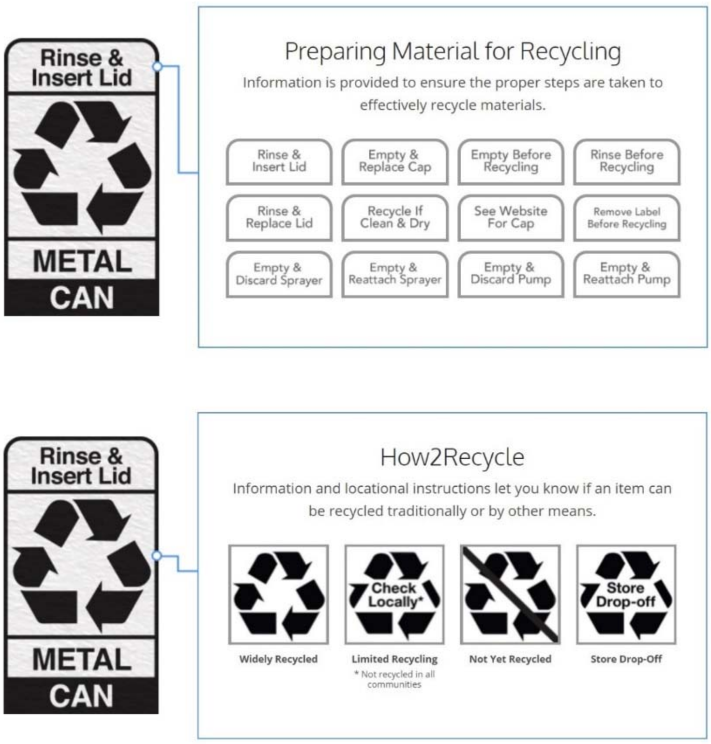

Figure 20: Examples of labels and how to interpret them. Source: https://how2recycle.info/labels

6.3 Kamikatsu, a Japanese zero-waste town

Kamikatsu is a town with around 1500 residents situated in rural Japan. Its residents are expected to sort their waste in 45 different categories, and all waste must be brought personally to the town's waste station (Figure 21). At this station, one can also get sorting guidance by the staff. This practice is a result of a goal set in 2003to become a zero-waste town by 2020. As of 2016, the town had reached a recycling rate of 81% [68]. Only a few items, such as single-use diapers and hygiene products, rubber and some plastic types are not recycled. Every home has been provided with a composter, so that all food waste is treated at peoples' homes. This system is undoubtably time consuming for the inhabitants, which on the other hand creates an incentive for generating less waste.

Figure 21: Some of the sorting bins at Kamikatsu's waste station [69]

7 Summary and discussion

The table below shows a comparison between the regions discussed in the report. General characteristics for each area are provided. Note that there are more nuances and local differences within each country. The overall picture is that the EU has the best recycling system of the three, while China performs the worst. However, recycling rates are measured differently, and there is variable access to data from the different regions. Often, materials collected and prepared for recycling are regarded as recycled, so a clear picture on what is efficiently recycled is hard to obtain. Imports and export of materials for recycling complicates this picture. Despite this, many cases have been investigated, which give some indication on best practices for recycling systems.

	China	**United States**	**European Union**
Collection system	Public bins and informal collection	Curbside collection	Curbside collection and drop-off points
Source separation	All recyclables co-mingled. Separate collection in informal system	All recyclables co-mingled	Usually multiple streams. Some streams available at curbside, others only at drop-off points
Financing	Informal system is self-financed. Flat fees on MSW collection.	Consumer fees on MSW collection. Often PAYT	EPR finance collection of packaging waste
Legislations	Mandatory recycling in a few areas. 48 cities have recycling targets to be met by 2025.	No federal legislations. 10 states have bottle-bills. Mandatory recycling in some cities.	Requirements for individual collection of certain materials. Recycling targets to be met by 2025 and 2035. EPR mandatory from 2023.

Ideally, all waste should be co-mingled and then separated with 100% accuracy in an automated facility. This removes all dependence on consumer behaviour, which can be complex to change and adapt collection systems to. However, the findings presented in this report indicates that this is not possible with today’s technology. Economy is also a limitation, as automated separation of all waste into clean streams has high operation costs and requires large equipment investments. Therefore, source separation conducted by the consumer is necessary to get good recycling rates. This demands that the consumer is willing to recycle and knows how to do it right. A system with streams that are pure enough to be sorted efficiently but not to inconvenient or complicated for the consumers should be the main focus when waste collection systems are developed. It is also important to remember that every consumer must adapt to the waste management system in its entirety, so changing the collection system for one type of recyclables might change the collection rates or contamination degree in a different stream. An example of this effect is that Swedish consumers recycled more when separate collection of food waste was available. Understanding how to develop a well-functioning collection system, we should summarize the findings for consumer behaviour and processing from this report.

Consumer behaviour

Most systems require the consumers to identify recyclable materials from non-recyclable materials as a minimum. Studies have shown that recycling efforts increases with age, and that people in small apartments recycle less than people in single-family homes. Moral obligation, knowledge about recycling and beliefs regarding environmental impact are factors that influence consumers’ willingness to recycle to some extent. However, two factors stand out to be the most influential across all regions: convenience and money. Below, measures to increase recycling participation by these factors are listed.

- Convenience is related both to time consumption and storage space
    - Single-stream collection is favoured as it decreases time and effort spent on sorting
        - Demands extensive central sorting
        - Many EU nations have both multi-stream recycling and high collection rates
    - Curbside collection or drop-off points near peoples' homes are favoured
        - Transportation cost and emission issues, especially in rural areas
- Possibilities of saving money from recycling increases participation
    - Deposit-return systems generally gives high recycling rates for beverage containers
    - PAYT rewards those who generate less residual waste (by recycling)
        - Needs control mechanisms because it also rewards contaminating the recyclables

Processing

In the systems investigated, Al packaging is not sorted separately by the consumer in any case, except for deposit-return systems for beverage cans. Therefore, some level of central sorting is required regardless of the collection system. Below, some strategies for separating Al from the waste stream are listed

- Automated sorting, diverting Al from other recyclables
    - Many different materials to be sorted in the same facility (the case for single-stream recycling) gives a higher chance for loss of Al and contamination of the Al recovered due to wrong classification
- Manual sorting
    - Could be more accurate than automated sorting
    - Hard to support economically, especially in high-income countries
- Automated sorting, separating Al from general waste
    - All waste must pass an eddy-current separator
    - Hard to support economically because of the low Al content in general waste
- Separating Al from bottom ash using an eddy current separator
    - Thin Al is lost to oxidation and fly ash
    - Small particles (<2-3 mm) are difficult to extract

Policy and economy

In addition to requirements from consumers and processing technology, collection of Al packaging must also adapt to local policies and economic prerequisites. In general, governments in the US and the EU *facilitates* recycling and *encourages* the public to participate in recycling. China seems to be more willing to *enforce* recycling on their citizens, like they now do in Shanghai. There are mandatory recycling laws present in parts of the EU and US, but they seem to be more reluctant to sanction people who disobeys these laws than China. In the EU, the focus in many countries is to make the producers responsible for packaging waste recycling trough EPR. The EU also has recycling targets that they require their member states to meet. The most important economic prerequisite is that the collection system must be able to collect materials as cheaply as possible, while ensuring that the materials are not too costly to process and that their quality is high enough to be sold for a sufficient price. Fees are also important here, both which type of user fee that the system utilizes and whether packaging producers must pay EPR-fees.

Material considerations

There are many contributors to loss of Al trough the value chain of Al packaging. Composite materials, alloys, imperfect sorting, oxidation and insufficient recovery from bottom ash are all examples that seems to be impossible to eliminate in a real-world waste management system. As it is practically impossible to recover 100% of Al packaging, one should aim to reduce the amount of packaging as much as possible in order to preserve natural resources and avoid emissions related to production of virgin Al. This can be achieved by reducing the thickness of the packaging. A paradox is that by reducing the thickness, one also reduces the recyclability of the material by larger oxidation rates. It is therefore important to divert Al packaging from incineration waste stream, especially when the packaging is thin. In many developed countries the situation is frankly the opposite. While beverage cans, which is made of thick Al is collected separately trough deposit systems, thin products such as household aluminium foil is rarely source separated.

Subjects for further research

Does a PAYT scheme result in more contamination unless it has control mechanisms? PAYT is a promising incentive to increase recycling. Its main drawback is that it creates an incentive to sort incorrectly or to dispose/incinerate waste illegally in the nature. This leads to the need of control mechanisms, which can be challenging to implement. Therefore, it could be useful to find out if consumers try to take advantage of the system, or if they are mostly compliant regardless of whether control mechanisms are in place.

How effective can MRFs be under normal operating conditions, and how is this dependent on the waste stream entering the facility? This report indicates that more source separation leads to less loss in MRFs and better quality of the Al scrap. However, this is built on just a couple of reports from specific facilities. Moreover, none of these facilities processed metal and glass only, which is the case in Norway.

Is automated separation of different Al alloys possible to do efficiently? Separation of different Al alloys provides less downcycling of the aluminium, and thus better material recovery. It is however questionable whether it is efficient in terms of economy and yield.

How does population density influence emissions and costs? This report has focused mostly on the main characteristics of three large regions and compared them. However, there are more aspects than those on the national level that can be interesting to examine. Especially how a collection system needs to be adapted differently for urban, suburban and rural areas. Though a standardized system for waste management on a national system might make it easier for product manufacturers and MRFs, it might be hard to make a system that is well functioning both in urban and rural areas. As an example, collection of many different waste streams might be harder to sustain financially in rural areas as the transport costs will increase.

Conclusion

There are many ways to design a collection system with a lot of factors influencing its performance. Therefore, a single best-practice example for collection of aluminium packaging has not been possible to obtain in this research. However, key factors have been identified and described, providing some knowledge that should be considered when collection systems are developed. Measures that seems to provide high recycling rates where they are implemented are deposit-return systems and EPR. Yet, there are examples of systems without these measures that show similar performance to those who do. This indicates that a system that is well designed and adapted to the conditions in the area it operates can perform well regardless of the specifics of the system.

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