

Review of WTE ash utilization processes under development in northwest Europe

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EXECUTIVE SUMMARY

The author is a doctoral student, working under the direction of Prof. Chris Cheeseman in the Civil and Environmental Engineering Department of Imperial College, London. The main subject of his thesis is the transformation of waste-to-energy (WTE) bottom ash to higher value applications. A second subject is the critical analysis of research and development efforts in Europe to advance beneficial uses of WTE ash. As part of this second part of his research, the author participated at the International Solid and Waste Association (ISWA) Working Group in Energy Recovery (WGER) meeting held in Bern, Switzerland on 25 and 26th October, 2012; and visited KEZO Himwil facility in Zurich, Switzerland as part of the ISWA meeting and Inascho facility in Rotterdam, Netherlands with Dr. Ralf Koralewska of Martin GmbH, during the period of October 26th, 2012 and December 5th, 2012 accordingly. This report summarizes the information received by the author during the above meetings and visits.

An important finding is the implementation of dry discharge technology in several plants in Japan and two plants, in Switzerland, Europe: SATOM Monthey WTE and KEZO Hinwil. The Dry Discharge system facilitates the recovery of metals, both ferrous and non-ferrous, and also minerals from incinerator bottom ash (IBA). Also, since water is not used, the weight of ash to be disposed (approximately 20% wt. less), and consequently, the cost of disposal (including transportation), is considerably less. In addition, dry discharge exhibits higher energy efficiency, lower total organic carbon (TOC) in the IBA, significant reduction of the leaching of IBA in landfills, and finally, by adding water under controlled conditions the chemical reactions can be activated.⁷

According to a research study by Dr. Leo Morf of the Office for Waste, Water, Energy, Air, Department of Waste Management in Zurich, the dry discharge method has shown 45% increase in ferrous metal recovery and 50% in non-ferrous metals, over the wet-discharge method⁷

The main disadvantage of this process is the generation of dust emissions by the very fine dry IBA particles, which needs special treatment. However, many industries, e.g. flour mills, cement plants and others, can manage dust issues in a sustainable manner. Prerequisite is a sealed transport system, in which many WTE industries are unfamiliar. Additionally, many WTE plant operators juxtapose dry discharge technology; advocating that the use of tertiary air flow through the discharger may create a problem to the combustion process, since there is lack of the water barrier and, thus, the dry discharge technology is characterized as open system, However, taking into consideration the fact

that the fine dust is transferred back to the combustion chamber through the tertiary air flow; the system is actually closed. Furthermore, the tertiary air flow completes burning of IBA; and by eliminating the very fine particles and recirculating them to the incinerator, advances the quality of IBA and makes the further treatment easier.

Wet discharge technology is the dominant method currently applied for IBA discharge in most WTE plants worldwide. Recent developments by Martin Gmbh proved that an alternative method of dry discharge of IBA can be used. The introduction of advanced innovative treatment systems for the discharged IBA has increased metal extraction efficiency and quality of residues for further uses in construction industry. However, there is still a significant fine fraction, dependent on the technology used, corresponding to approximately 45% of the total IBA, which does not exhibit acceptable properties for further use, creating a bottleneck for the sustainability of WTE worldwide.

Current research at Imperial College London by the author showed that the unsustainable fine fraction of IBA, which is disposed of in landfills, can be used as raw material for the production of glass ceramic composites to be further used in the construction industry.

The production of higher value construction materials from the fine unsustainable fraction of IBA represents a particularly attractive reuse application for IBA (Owens and Newman et. al, 1999).

The manufacture of higher value construction materials from IBA is expected to be viable because:

- i) Due to the increase of Landfill tax, as well as the EU Landfill Directive, the cost of disposing IBA to landfills increases and new sustainable solutions for the utilization of IBA should be implemented.
- ii) There is a limited availability in natural derived construction materials; therefore, construction materials are transported over large distances, increasing the cost of production.
- iii) There is a tendency for WTE plants producing IBA to be located in urban areas, close to where extensive construction activity is occurring. A potential source of higher value construction applications is therefore available close to where these materials are most needed.
- iv) The manufacture of higher value construction materials from negligible cost waste, offers opportunities for developing products with improved thermal and sound insulation properties.

Therefore, by the sustainable treatment of the fine fraction of IBA; a closing loop of circular economy for WTE will be achieved; and by examining the potential for further extraction of metals from the fine fraction, a sustainable solution with multiple benefits can be reached.

1. Waste management situation in Switzerland and the Netherlands

1.1. Waste management in Switzerland

Switzerland is a federal republic consisting of 26 cantons. It has borders with Germany to the north, France to the west, Italy to the south, and Austria and Liechtenstein to the east. Its population, according to a 2012 estimate by the Swiss Federal Statistical Office, is 8 million and its area is 41,285 km². The Swiss Confederation has a Gross Domestic Product (GDP) in Purchasing Power Parity (PPP) basis of \$ 51,262 per capita¹.

Switzerland spends 0.6% of its GDP for waste management, in comparison to 11.4% for health care. The generation of municipal solid waste (MSW) amounts to 5.2 million tons annually corresponding to 0.65 tons per capita. Of the total MSW, 33.8% is recycled, 16.7% is composted and 49.6% is incinerated with energy recovery. There is no landfilling^{1,2,3}. As explained in the APPENDIX II, Switzerland belongs to the countries, which have high relative GDP per capita (in PPP basis) and high relative degree of sustainable waste management.

A large contributor to this achievement has been the publication in 1986 of 'Guidelines of waste management in Switzerland', by a broad coalition of stakeholders, such as representatives of industry, science, non-governmental organizations (NGO) and waste management authorities³.

The basic points of the guidelines are as follows^{1,3}:

- Waste management is guided by the objectives of the laws protecting public health and the environment.
- All waste disposal methods must be environmentally compatible (life-cycle-thinking).
- Switzerland's aim is to dispose of its waste within its own territory.
- Public authorities play a subsidiary role in waste management.
- Every disposal system for waste shall generate only two types of products:
 - i. recyclable substances
 - ii. residues for final storage
- No passing on of problems to future generations
- No passing on of problems to other countries
- Specific materials waste streams are to be separately collected for recycling only:
 - i. If there is an ecological benefit, as compared to disposal of the waste and subsequent use of new resources, and
 - ii. If the costs for separate collection and recycling are economically reasonable.
- The financing of the recycling must be assured in the long term.

- Paper, cardboard, glass, PET-bottles, used beverage cans and scrap metals should be recycled.

The Swiss Confederation hierarchy for waste management is similar to that generally accepted in other developed countries: ^{1,3}:

1. Minimization of waste at the source, by prevention and by the use of non- or low-waste technologies.
2. Reduction of hazardous substances in products and processes.
3. Waste reduction through improved reuse and recycling.
4. Treatment of the unrecoverable waste in an environmentally sound manner within Switzerland.(by thermal treatment with or without energy recovery)

By federal law, the waste management authorities in Switzerland are the 26 Cantons.. Most Cantons delegate this duty to communes (local authorities). Recyclables and the remaining mixed urban solid waste (MSW) of households, trade and commerce is collected either by the communes, by local associations, or by private companies acting on behalf of local authorities ^{1,3}.

Since 2000, when the ban for landfilling of untreated waste (municipal solid waste, non-recycled demolition waste, and sewage sludge) was implemented, sustainable waste management has made a lot of progress Recycling, composting, and Waste-to-Energy (WtE) rates have increased rapidly over the last decade ^{1,2,3}.

The first waste incineration plant in Switzerland was built in Zurich in 1904(MSWI Josefrasse). In 2009, 30 waste incinerators were in operation treating 2.6 million tons of MSW and generating 1,900 GWh of electricity (0.7 MWh/ton) and 3,000 GWh of heating (1.2 MWh/ton). Their emissions are well below the national standards, resulting in a high degree of public acceptance ^{1,2,3}.

Switzerland has no fossil fired power plants or large metallurgical furnaces. .Cement kilns already obtain more than 50% of their fuel requirements from waste (used motor oil, solvents, sewage sludge, bone meal, plastics). Mechanical biological treatment (MBT) has not been very attractive, over incineration of trash, because of short transportation distances to the nearest MSWI (WTE) plant ^{1,2,3}. Wood waste is used as fuel in energy recovery plants.

Therefore, incineration is the only viable sustainable solution, focusing on the recovery of resources, especially of metals, and on improving energy production.

In Switzerland, novel incinerator bottom ash (IBA) as well as fly ash treatment technologies have been developed. The processes mainly focus on the enhanced recovery of metals from bottom and fly ash. For the treatment of IBA, a dry discharge

method has been developed that includes magnetic separation of iron followed by Eddy Current separation of non-magnetic metals, as discussed in a later section of this report.

The main target for fly ash processing is to eliminate PAH and dioxins contained in it, by means of flotation to separate soot particles containing PAH and dioxins. In addition, volatile metals in the ash are recovered from the hydrochloric acid solution of the wet scrubber^{1,3}.

All sewage sludge is being incinerated in Switzerland and about 80% of wastewater treatment plants (WWTP) are equipped for recovery of phosphorus by precipitation.

In general, the main elements of waste policy framework in Swiss Confederation are ^{1,3}:

1. Comprehensive legal framework, including provisions re-financing of waste management, i.e. advance disposal charges.
2. Separation of hazardous and household waste streams.
3. Modern waste disposal infrastructure in all regions.
4. More than 50% of urban solid waste is recycled
5. Since 2000, there is a ban on landfilling of untreated wastes (municipal solid waste, demolition waste, and sewage sludge).
6. All incinerators are equipped with advanced air pollution control systems and their emissions are lower than the Swiss and E.U. standards.
7. Effective public-private partnerships.
8. Awareness of need for waste minimization.

1.2. Waste management in the Netherlands

The Netherlands borders are the North Sea to the north and west, Belgium to the south, and Germany to the east. This nation shares maritime borders with Belgium, Germany and the United Kingdom. It is a parliamentary democracy with its capital city in Amsterdam and the seat of government is The Hague. The Netherlands is often referred to as 'Holland', although North and South Holland are actually only two of its twelve provinces ⁴.

Its population is 16.7 million and its area 41,543 km². The GDP per capita (in PPP basis) is \$42,772. The Netherlands spend 0.5 to 1% of their GDP for waste management ⁴. The generation of MSW is 9.9 million tones MSW per year (0.59 ton per capita), 32.9% of which is recycled, 27.7% composted, 38.9% is incinerated with production of energy and only 0.4% is landfilled ². As explained in the APPENDIX II, the Netherlands belongs to the countries, which have high relative GDP per capita (in PPP basis) and high relative degree of sustainable waste management.

Lack of space and a growing environmental awareness forced the national government to take early measures for reducing landfilling of waste. In 1994, the Netherlands incorporated into their legislation the 'Lansink's ladder', which was later adopted by the European Parliament to form the 'waste hierarchy' in the European Waste Framework Directive⁵.

'Lansink's ladder' requires the prevention of waste generation to the maximum extent, the recovery of valuable raw materials (recycling), and the generation of energy by combusting the remaining waste. If any of the above approaches are not applicable, only then the landfill of the waste is allowed, but only in sanitary landfills. It should be noted that the Dutch people are very sensitive with respect to the sustainable waste management. According to surveys conducted by Dutch authorities, more than 90% of Dutch people separate their household waste into recyclables and trash ⁶.

When the landfill tax was introduced in 1995 it was set at €13/ton. In 2000, two different levels of taxes were introduced. The starting point was that landfilling is always charged with a high tax, because it is assumed that incineration is an alternative to landfilling for all waste except for waste with a density greater than 1,100 kg/m³ that is assumed to be non-combustible and, therefore, can be landfilled at a lower tax. In 2005, a considerable increase to €85/ton came into effect for combustible trash, while the low tax only increased by €1 to 14/t. A tax on incineration also exists but is currently set at zero ⁶.

Currently, the landfill tax is structured as follows:

- High tax: Banned waste landfilled with a permit: €107.49/ton ⁶
- Low tax: Inert waste (not banned) €16.79 /ton

The Landfill tax is collected by the landfill operators, along with payment of the gate fee. The tax is passed on to the Dutch finance ministry. The simplicity of this system means compliance is close to 100% ⁶.

Due to insufficient incineration capacities, until 2005 waste-producers had to choose between export to neighboring countries or the acceptance of increasingly high landfill costs in the Netherlands ⁶. To avoid the landfill tax, in the period 2002 - 2005, a lot of combustible waste was shipped to Germany for landfilling. This ended with the implementation of a landfill ban in June 2005 in Germany. In January 2007, Netherlands opened their borders for the incineration of waste (both household and commercial/industrial) but closed them for the landfilling of combustible waste. This action was taken to stimulate the construction of further incineration capacity in the Netherlands but so far there have been few significant quantities of cross border trade in combustible waste ⁴⁻⁶.

The Netherlands have 11 operating WTE plants, incinerating 6.9 million tons of waste (3.8 million tons of MSW) annually and producing 4.09 MWh of electricity (0.59 MWh/ton) and 0.78 MWh of heat (0.2 MWh/ ton)⁴⁻⁶.

The WTE bottom ash is mainly used as road construction material and for landfill maintenance after enhanced recovery of metals with innovative approaches, as explained later in this report. The Air Pollution Control residues (APC; "fly ash") are mainly disposed in salt mines or hazardous landfill sites and also as filler in asphalt ⁴⁻⁶

2. Discharge of incinerator bottom ash

Incinerator bottom ash (IBA) contains about 9% of ferrous scrap, 63% of sintered ash and slug, 8% of stones and others, 18% of glass/ ceramic, 1% of non-ferrous metals (mainly aluminum) and 1% unburned MSW⁷⁻⁹; the latter depends on operating conditions in the combustion chamber⁷⁻⁹.

There are currently two types of discharge systems, the wet and the dry discharge.

2.1. Wet discharge of IBA

Traditionally IBA drops from the end of the moving grate into a water tank below the furnace, wet discharging the IBA. Temperature and water absorption of IBA control the water consumption. Typically, the amount of water provided to the discharger is sufficient to quench the IBA; and thus, recirculation or overflow of water is not required.^{9,12}

Usually, the discharger is filled with water and a constant amount of bottom ash up to the level of the front air sealing wall; creating an air seal against the furnace and therefore preventing flue gas and thermal pollution in the basement and false air ingress into the boiler. The discharge rate in field of waste combustion ranges within 4.5 to 12.0 m³/h.^{9,12}

The discharging ram forces IBA under the air sealing wall towards the drop-off edge; without creating any dust or odors. There is a drain-off section before the drop-off edge where excess water is extracted by the compressing action of the discharging ram. IBA is therefore moist rather than wet when discharged.

The discharger is driven either by a separate or a central hydraulic unit. When the water comes in contact with the heterogeneous IBA, there are many uncontrolled chemical reactions which result in poor quality of IBA.

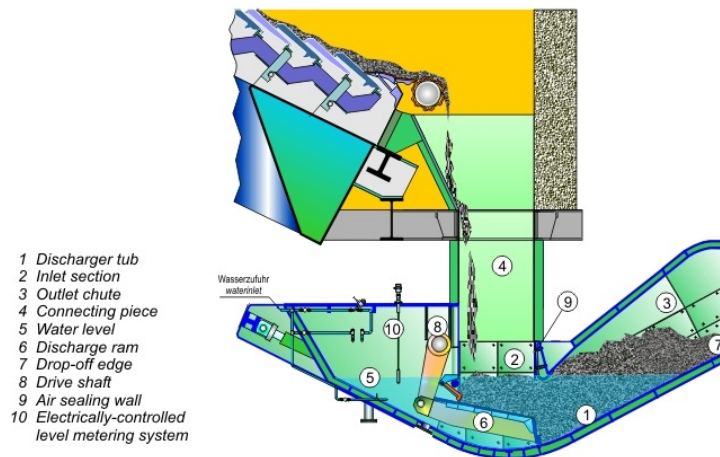


Figure 1. Schematic of wet discharge IBA ⁶

2.2. Systems under development for Dry Discharge of IBA

Nearly all WTE plants in the world use the wet discharge method. In 2002, the WTERT organization at Columbia University (www.wtert.org) studied the potential for dry ash discharge and published the results of their study at the 2003 NAWTEC proceedings. In 2000, Martin GmbH applied a dry ash discharge technology at the Iwaki Nanbu WTE plant in Japan. Currently there are six WTE plants in Japan using the dry discharge technology; it is also used at the KVA Monthey WtE plant in Switzerland. Additionally, another type of dry discharge technology is applied in KEZO plant in Switzerland. These technologies are described in the following sections ⁷⁻¹¹.

2.2.1. The KEZO dry discharge system

Waste incineration plant of Zurich upper city (KEZO in German) developed a few years ago a technology to discharge the bottom ash dry which finally allows access to particles smaller than 5mm, containing more NF precious material than fractions with bigger particles. The dry bottom ash is a free flowing material and therefore allows the best possible separation and quality of metals and minerals (Fig. 2 ⁷⁻¹¹).

IBA passes through an ash drum and falls onto a baffle plate to be comminuted further. In front of this equipment there is a set of flaps, that serve to reduce the flow of air through the system, and a water sprinkler used to quench any still burning embers, if necessary. The ash is discharged onto a vibrating conveyor, designed to withstand temperatures up to 400 C. The ash discharge is monitored with a camera and has a 2-way diverter for the removal of the material in emergency. Any pieces that are too big can be removed through an electrically operated hood.

The ashes are air-cooled during discharge by injecting tertiary air, which is an additional process variable for dry discharge. However, it should be noted that the total air input to

the furnace is not increased; the secondary air is reduced by the amount of tertiary air used in the dry quenching process. The tertiary air also supports afterburning of any organic compounds remaining in the dry –discharge ash, which can be as much as 0.3% of the ash. Very fine particles entrained in the tertiary air are returned to the furnace.

The vibroconveyor transports the crushed ashes at the end of the discharge to a screen that separates oversize particles (>5mm). The undersize ash is then processed as in the conventional wet discharge process, as described in a following section.⁷⁻¹¹

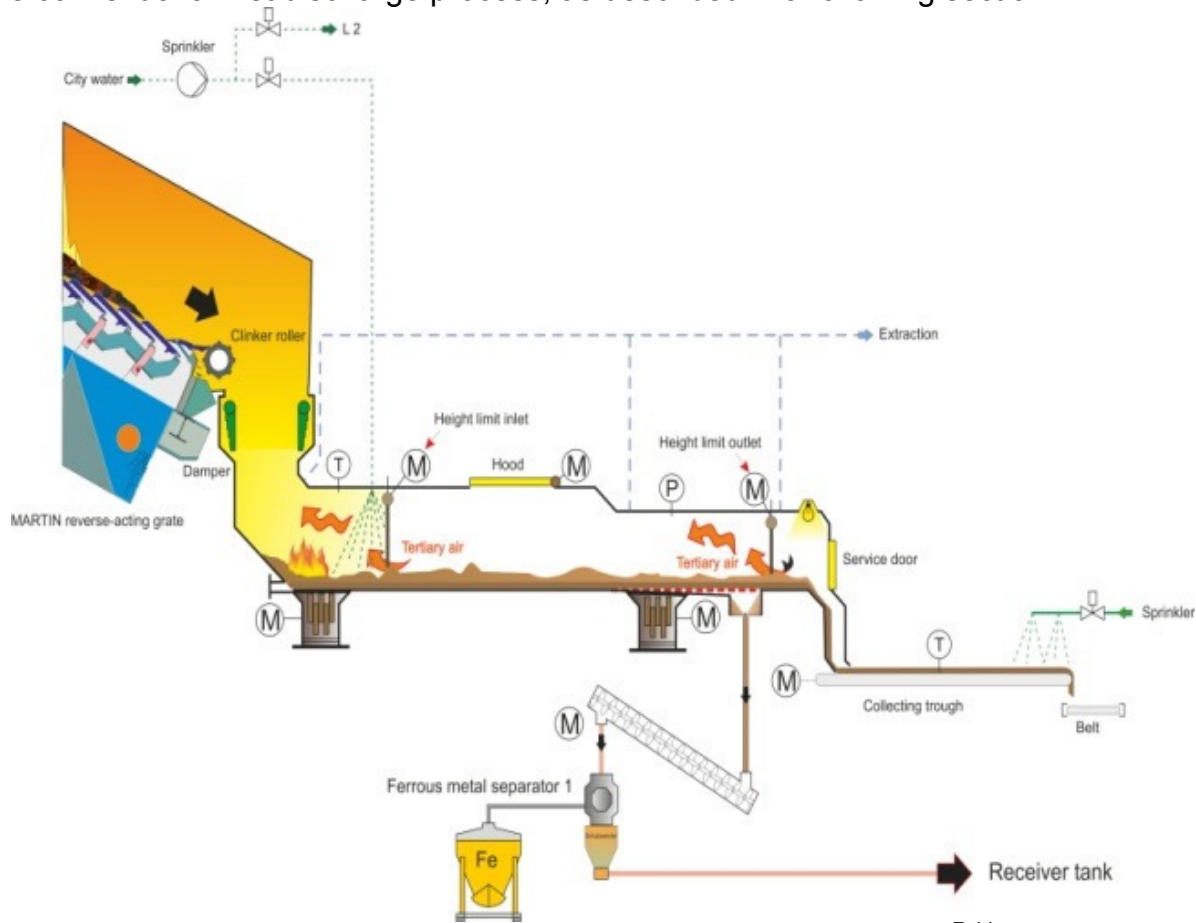


Figure 2. Schematic of KEZO dry discharge system⁷⁻¹¹

The KEZO facility in Hinwil (Figure 3) is a special ‘tunnel’-type separation process using sieving technology and resulting in dedicated separation of fractions with high metal content. It uses different fractions of sieves, 0.2 to 0.7 mm, 0.7 to 5.0 mm, 5.0 to 20.0 mm. The separation efficiency of the plant is up to 95 % and for the non-ferrous content in the 0.7 to 5.0 mm fraction is more than 5%. The technology for the separation of non-ferrous metals includes two slanted eddy current separators, with overall efficiency 96.8%. However, around 0.2% of NF metals still remain in the mineral fraction of fine bottom ash. The mass flow of KEZO plant is illustrated in Figure 4. The mineral fraction is 85.8%, the ferrous 11% and the non-ferrous 3.2%. In total, the ferrous metal efficiency is 81.7% and the NF is 26.5%^{10,11}.

The plant produces two aluminium and two NF precious metal fractions with particle sizes from 0.7 – 3.0 mm and 3.0 – 5.0 mm. 100 tons of aluminium were exported in 2011 to smelting plants that produce raw materials for casting houses from the two fractions. 22 tonnes each of fine and coarse NF precious metal fractions were also produced during 2011. According to analyses both fractions have a similar proportion of precious metals ¹⁰. The concentration of various metals to a high degree is being enabled; the copper content in both fractions, for instance, is more than 60 %. Both fractions were shipped to a precious metal smelting plant for processing.

The plant is a project of Zurich waste recycling association, ZAV. The plant's capacity is designed to cope with the bottom ash from all of the incineration processing plants in the canton of Zurich. In Switzerland approximately 700,000 tons of incinerator bottom ash (IBA) is being produced each year, giving this novel technologies a great potential ^{1,3,10,11}.

As of the end of 2013 the dry discharge method will be applied to the bottom ash from all of the furnace lines at the KEZO incineration plant in the Zurich Oberland region and treatment of the coarse fraction will take place as well. An industrial bottom ash processing plant will be taken into operation at the same time. ^{10,11}.

The main advantage of KEZO dry technology is that IBA has better quality than the conventional wet technology, since the leaching rate is reduced, for example copper leaching is reduced by 99%. Additionally, it exhibits higher efficiency of metal recovery, and reduces the weight by 20% making it easier to transport. Regarding NF-metals there is no disintegration and the precious metal particle is easier to separate ^{10,11}.

According to KEZO financial report, in 2011, the main income came from 20 donors, amounted to \$1,065,789, and the total expenses were \$762,945, of which \$10,612 were the operation expenses and \$106,112 were the equipment costs. The maintenance/ optimization costs were negligible ¹¹.



Figure 3. IBA dry discharge technology in Hinwil, Zurich⁸

The mass flow of the Hinwil KEZO plant appears in the following diagram:

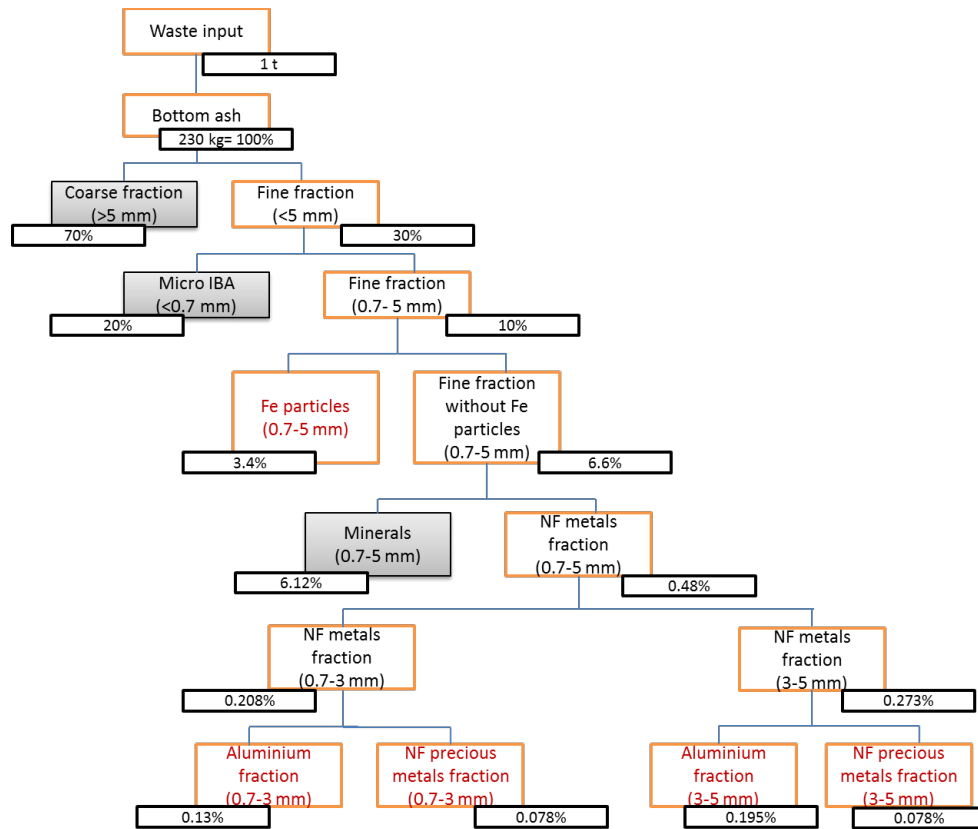


Figure 4. Mass flow of KEZO IBA treatment (grey colored box: landfill; Bold red letters: sent to melting plants)⁸

2.2.2. The Martin dry discharge system

The main components of Martin dry discharge and particle sorting system are a discharger, an air separator, a dust removal system and an air system; and are operated without the use of water.

IBA is dry discharged and is directly transferred by means of gravity and mechanical vibration to an air separator. This results to separation of IBA in three product streams:

- Coarse fraction and recoverable metals
- Fine fraction
- very fine fraction (dust)

Martins dry discharge system uses a fully sealed air separator area applying negative pressure through the air supply system; to prevent air leakage into the furnace and dust emission into the combustion chamber.

An ash removal system (e.g. a cyclone separator) is used to separate the fine fraction from the air separator's exhaust air. As part of the secondary air system, the exhaust air and its dust content are fed into the combustion process.

The technology results in a metal enriched coarse fraction (>1 mm); and a nearly metal free fine fraction (<1 mm) for reuse. The process separates the ash into minerals (80%), ferrous metals (11.6%) and non-ferrous metals (8.4 %). The coarse fraction can be recycled and used in road construction. The fine fraction can be recycled into the furnace.⁷⁻¹¹

The Martin technology in combination with the air separator is a compact and robust process. A schematic of this process is shown in Figure 3 and a mass flow diagram of the treatment of IBA in Figure 4.

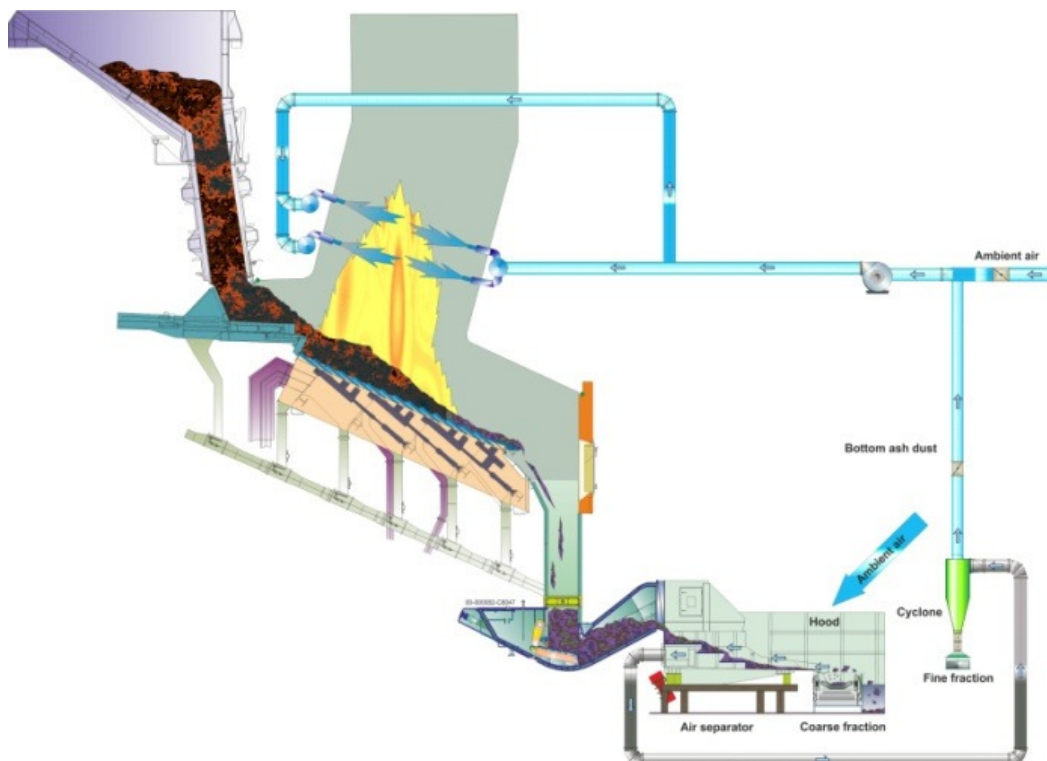


Figure 5. Martin's dry discharge system^{7,8}

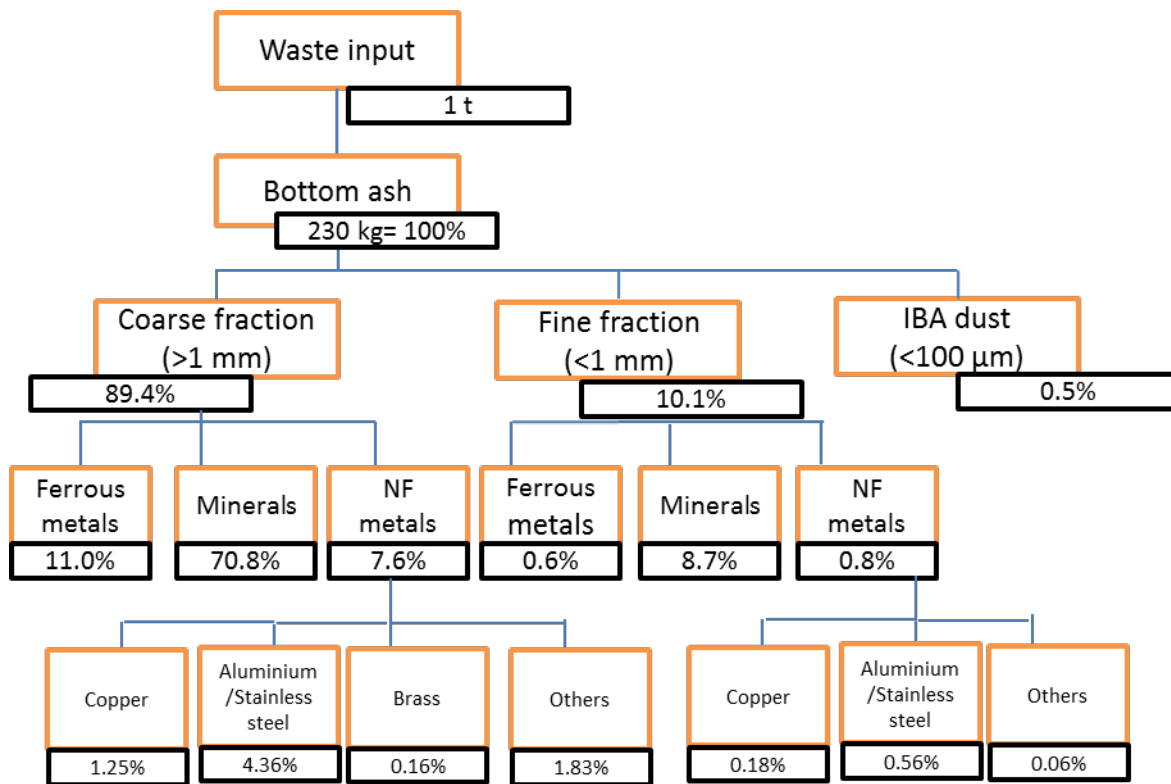


Figure 6. Martin bottom ash dry discharge mass flow; Monthey WTE plant ^{7,8}

2.3. Comparison of Martin and KEZO dry discharge systems

Table 1 compares the characteristics of the two dry discharge systems.

Table 1. Comparison between Martin and KEZO dry discharge IBA system ^{7,8}

Characteristics	MARTIN system	KEZO system
Separation	Air separator (by mass)	Screen separator (by size/shape)
Metal separation	> 1 mm/ < 1 mm	>5 mm/ < 5mm
Air seal to the furnace	Yes (bottom ash column/ subpressure in hood)	No
Separation combustion control -bottom ash discharge	Yes	No
Bottom ash comminution	Yes(air separator steps)	Yes(baffle plate)
Bottom ash cooling	Yes(air separator)	Yes(dry discharging system)
Energy recovery	Yes (secondary air)	Yes (tertiary air/ post combustion)
Recirculation of bottom ash dust	Yes (secondary air)	Yes(tertiary air/ post combustion)
Wet bottom ash discharge	Possible	Not possible (extinguishing system)

It should be noted that this study showed that there is active interest in converting from wet to dry discharge systems in Switzerland, Germany, Austria and the Netherlands.

3. Treatment of IBA

IBA from Municipal Solid Waste Incinerators (MSWI) is generally quenched immediately after exiting the furnace. The result is a moist, agglomerated material, in which the finer particles are strongly bound by water bridges. These features make it difficult to process the material below a grain size of 8 mm. In order to recover metals and minerals from the ash down to very fine particle sizes, the material should either be dried to eliminate the water bridges or immersed in water to obtain slurry with freely moving particles. Drying the ash requires a considerable amount of energy; 750-1000 MJ of energy per tonne since the water amounts to about 150 to 200 kg per tonne. Furthermore, for the production of mineral products, it is important to reduce the soluble chloride and sulphate contents, which is difficult starting from a dry material. Wet physical processes are also generally superior for separating organic and heavy metal particles because they allow more efficient and accurate classifications based on size and density.

MSWI bottom ash treatment in Europe usually involves one of four basic solutions:

- Landfilling, possibly after partial recovery of ferrous and non-ferrous metals (>10 mm) by dry physical separation (magnetic and eddy current separators) (Switzerland, Italy).
- Partial recovery of ferrous and non-ferrous metals (>10 mm) by dry physical separation, followed by use of the residue in infrastructure (the Netherlands, Germany, France).
- Deep dry recovery of metal particles (>4 mm) by dry physical methods, followed by use of the residue in infrastructure (Denmark).
- Wet treatment of the bottom ash to remove organics and metals down to 0.1 mm, producing at the same time a clean aggregate for the building industry (the Netherlands).

Bottom ash is commonly separated by dry physical methods (coarse screening, size reduction, magnetic separation, eddy current separation) and using aging or washing to stabilize the residue in terms of leaching capacity.

The following section presents the methods currently applied for the separation of metals from IBA.

3.1 Traditional separation of metals

Traditionally, moist IBA is subjected to ferrous and non-ferrous metal separation in many countries, such as Denmark, France and Germany. It is applied for the recovery of steel, coarse aluminium and copper-alloy particles (larger than 10 to 15 mm) from IBA. However, this process recovers only part of the metals in the ash, while fine ferrous and non-ferrous metals are not recovered. Also, in plants using eddy current separation, due to the high moisture content of the IBA, the separation efficiency of the fine particles (<2 mm) is rather poor with more than 3 kg of heavy non-ferrous metals (HNF) lost per

ton of IBA. These traditional “dry” separation processes require a capital investment cost of \$3-6 million for a plant of 500,000 tons per year capacity^{7, 10-12}.

3.2 “Wet” separation of metals

MSWI BA combusted at AEB in Amsterdam is separated on –site using a basic dry BA treatment. The main purposes of this step are to remove the ferrous scrap, return the large, ill-burnt pieces back to the incinerator and reduce the size of the ash to below 40 mm. The installation also recovers most of the coarse (>15 mm) fragments of non-ferrous metals. 7.4% is ferrous scrap; 1% is the non-ferrous scrap.

Additional to the dry process described in section 2.1.1, AEB plant applies the wet IBA treatment method.

Rem et al. invented the “wet” IBA process in 2004, which was applied at the AEB Amsterdam WTE plant in the Netherlands, for the treatment of very fine particles that is up to 100 µm. The pilot plant was built in 2004 at the existing soil-washing plant of the Municipal Waste Processing Service. The process involves the wet screening of IBA into several fraction streams that are treated separately for non-ferrous recovery: the less than 2mm, 2 to 6 mm, 6 to 20 mm and 20 to 40 mm. The less than 2 mm stream is fed into a cyclone to remove the less than 45 µm sludge. However, this fraction is treated in a typical soil cleaning process, which is considered to be rather expensive. A schematic of the process applied in AEB WTE plant is presented in Figure 5.

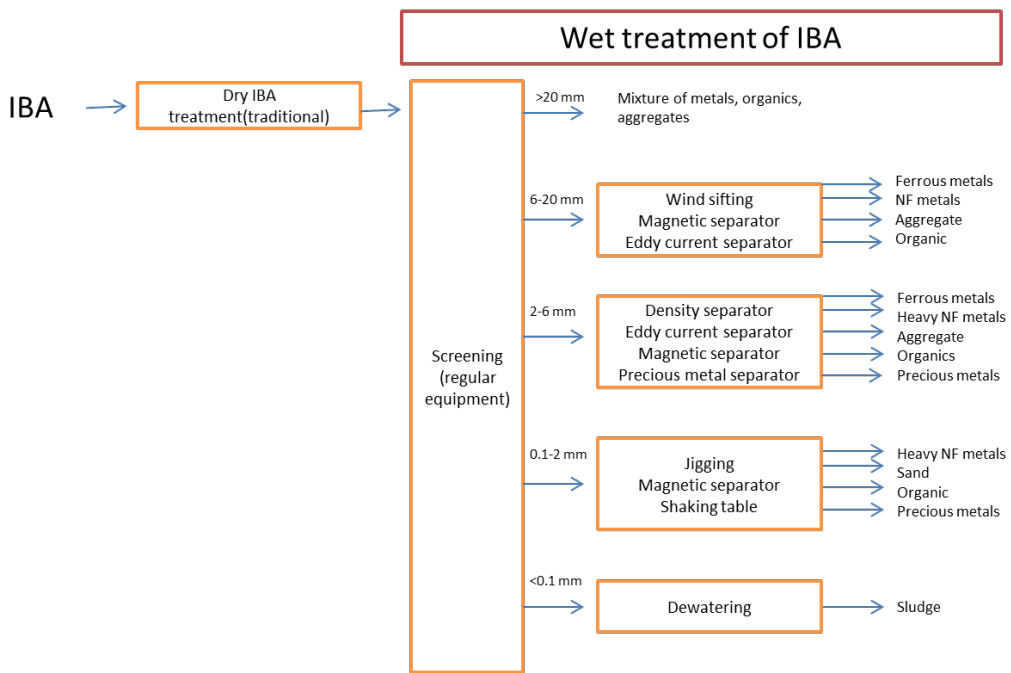


Figure 7. Schematic of AEB IBA treatment⁴⁻⁷

The main advantage of this process is the reduction of the contaminants in the residue, except from antimony. The wet treatment process leads to the recovery of 6% (by weight of IBA) of ferrous metal and 1% of non-ferrous metals; 39% of IBA is used in construction, 45% is used as an alternate daily cover in landfills, 8% other uses and 1% is non-combusted material that is returned to the WTE furnace. However, 2.5 kg of HNF less than 2 mm is lost per ton of IBA. A mass flow of the process is presented in Figure 6. The “wet” treatment process estimated investment cost for a capacity plant of 500,000 tons per year is 12.9 to 25.6 million dollars⁴⁻⁷.

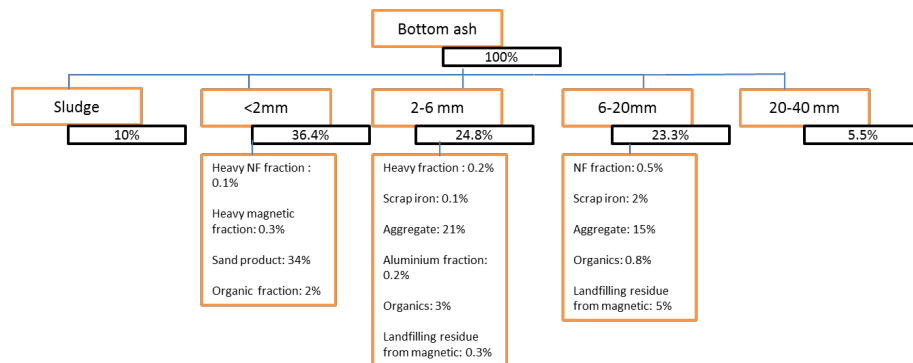


Figure 8. Mass flow of wet screening of IBA⁴⁻⁷

3.3 Inascho process

Collaborating with Delft University of Technology (TU Delft), INASHCO developed a new bottom ash dry treatment plant in 2008.

The process is able to recover metal particles down to 1 mm. Inascho collaborated with the AEB WTE plant in 2012. The process involves a semi-mobile installation producing a non-ferrous metal concentrate, a steel scrap concentrate and – due to its high efficiency – mineral aggregate in various size classes with immediate added value for the building and construction sector. INASCHO process can effectively treat IBA with moisture content up to 20%¹⁰⁻¹³.

The process consists of a concentrator and an upgrading facility.

The moist bottom ash is sized by ordinary screens at a size typically between 12 to–20 mm. Steel and non-ferrous metals are recovered from the coarse (+12 to +20 mm) product using the traditional processes. The remainder, without any form of drying, is brought into contact with the Inashco concentrator. The very fine metal contaminants (< 1 mm) and mineral particles (< 2 mm) are separated from the bottom ash in a physical classification step without the use of water, chemical additives or drying energy. Inascho estimated the investment cost for a capacity plant of 500,000 tons per year to be 4.5 to 9 million dollars¹⁰⁻¹³.

The advantage of this technology is it can be used as an extension to existing installations, meaning it can be added to conventional technology (screens, magnets and eddy current separators) to improve the non-ferrous metal recovery by 50% to 100%. However, there is still a very fine fraction (<0.7 mm), which remains untreated and disposed of to landfill ¹⁰⁻¹³.

4. Conclusions/ Recommendations

Wet discharge technology is the dominant method currently applied for IBA discharge in most WTE plants worldwide. Recent developments by Martin Gmbh proved that an alternative method of dry discharge of IBA can be used. The addition of innovative treatment systems for the discharged IBA has increased metal extraction efficiency and quality of residues for further uses in construction industry. However, there is still a significant fine fraction, dependent on the technology used, corresponding to approximately 45% of the total IBA, which does not exhibit acceptable properties for further use, creating a bottleneck for the sustainability of WTE worldwide.

The production of higher value construction materials from the fine unsustainable fraction of IBA represents a particularly attractive reuse application for IBA (Owens and Newman et. al, 1999). The manufacture of higher value construction materials from IBA is expected to be viable because:

- i) Due to the increase of Landfill tax, as well as the EU Landfill Directive, the cost of disposing IBA to landfills increases and new sustainable solutions for the utilization of IBA should be implemented.
- ii) There is a limited availability in natural derived construction materials; therefore, construction materials are transported over large distances, increasing the cost of production.
- iii) There is a tendency for EfW plants producing IBA to be located in urban areas, close to where extensive construction activity is occurring. A potential source of higher value construction applications is therefore available close to where these materials are most needed.
- iv) The manufacture of higher value construction materials from negligible cost waste, offers opportunities for developing products with improved thermal and sound insulation properties.

Therefore, by the sustainable treatment of the fine fraction of IBA; a closing loop of circular economy for WTE will be achieved; and by examining the potential for further extraction of metals from the fine fraction, a sustainable solution with multiple benefits can be reached.

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APPENDIX: Comparison between wet and dry discharge of IBA

The Dry Discharge system facilitates the recovery of metals, both ferrous and non-ferrous, and also minerals from WTE bottom ash. Also, since water is not used, the weight of ash to be disposed, and consequently, the cost of disposal, is considerably less. In addition, dry discharge offers the following advantages;

- + No wastage of water
- + Higher energy efficiency
- + Lower organic content in the bottom ash
- + Significant reduction of the leaching rate of bottom ash in landfills
- + Transport costs reduction because there is no use of water (20% of the weight).
- + If needed the chemical reactions can be activated at any time by adding water under controlled circumstances ^{7,8}

According to a research study by Dr. Leo Morf of the Office for Waste, Water, Energy, Air, Department of Waste Management in Zurich; the dry discharge method has shown 45% increase in ferrous metal recovery and 50% in non-ferrous metals, over the wet-discharge method⁷

The main disadvantage of this process is the dust emission generated by the very fine dry bottom ash particles. Therefore, special care is needed. However, this is a minor problem because there are many industries, e.g. flour mills, cement plants and others, which are able to handle dust issues effectively. Of course, a closed transport system is necessary which is not common as yet in the incineration industry. Also, for many furnace operators, the need for tertiary air flow through the dry bottom ash discharger is seen as a problem. The furnace operators prefer a closed system and, since the water barrier is not present, the dry-discharge system is considered to be an open system. The answer is that the tertiary air flow that carries fine dust and is conveyed back to the furnace actually closes the system in another way than the water seal. It should also be considered that the tertiary air flow completes burning of the ash and by removing the very fine particles and returning them to the furnace results in a higher quality ash and easier recovery of metals.

The characteristics of the wet and dry discharge processes for WTE bottom ash are compared in Table 2.

Table 2. Comparison of wet and dry discharge processes for WTE ash ^{7,8}

Criteria	Wet discharge	Dry discharge
Cooling	Rapid	Slow
Chemical reactions with water	Yes	No
		Hardening ability/ mineral phases
Metal loss due to oxidation	Yes, to a limited extent	No
Loss on ignition/ organic carbon content	Status quo	Lower
Leaching properties	Status quo	Improved
Weight	Water content of approx. 15-20%	Approx. 15-20% less than wet discharge
Adhesion of mineral particles on metals	High	Very low
Dust emission risk in absence of air control system	Low	High
Bulk material/ granulometry	No	Yes
Metal corrosion potential	Moderate	No

APPENDIX II: Sustainable Waste management matrix

Major waste management sustainability metrics include low cost, in terms of affordability in a competitive world; resource availability, and environmental impacts.

Using the statistics provided by Eurostat, CEWEP and from each country's waste management data, the global waste management matrix is presented in Figure 9. The x-axis is the relative GDP per capita of each country (in a PPP basis) and the y-axis is their relative degree of sustainable waste management, which was calculated according to the formula:

$$r = 1.2 * (\text{Recycling} + \text{Composting}) \% + \text{WtE} \%$$

where WtE includes MBT facilities.

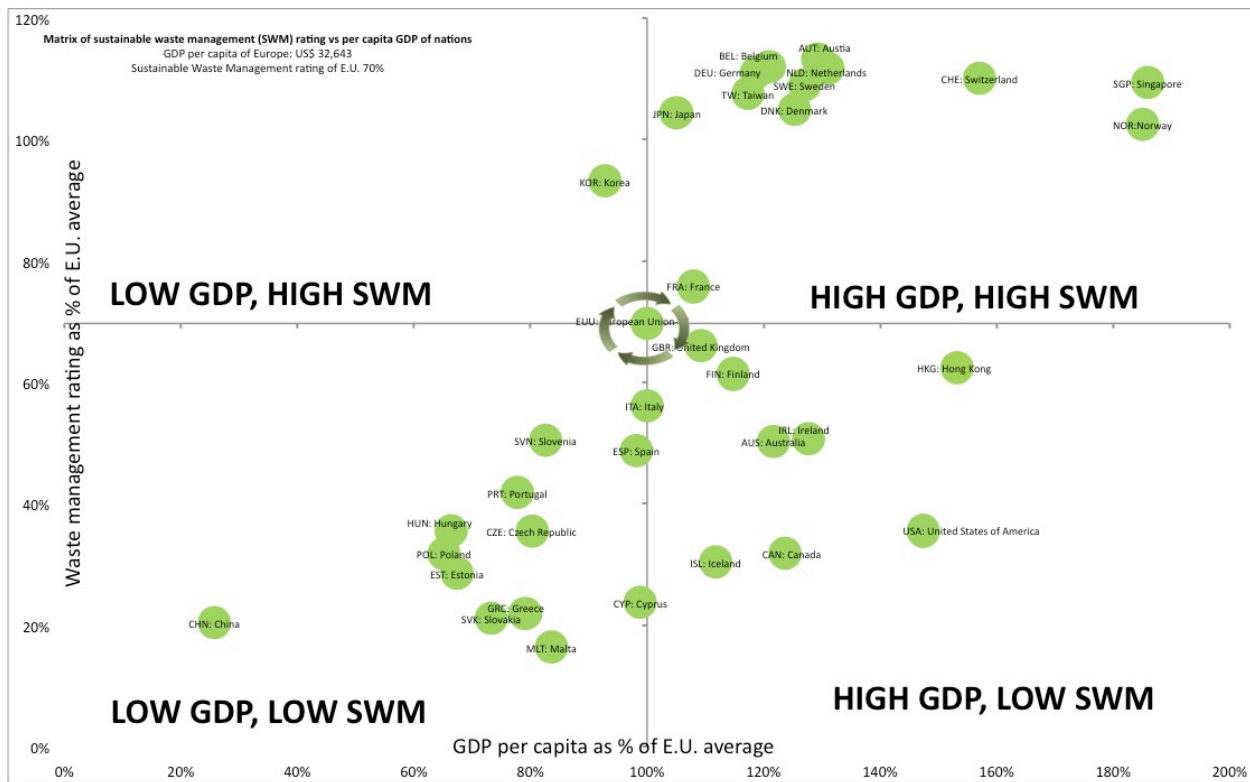


Figure 9. Matrix of level of Sustainable Waste Management (SWM) as a function of per capita GDP (PPP basis; EEC)

